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A Review Of Literature

On

HARVESTING, HANDLING, STORAGE AND TRANSPORTATION OF APPLES

U.S. DEPARTMENT OF AGRICULTURE
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A REVIEW OF LITERATURE ON
HARVESTING, HANDLING, STORAGE, AND TRANSPORTATION OF APPLES

A digest of contributions to the knowledge of biological phases of the subject published from 1945 through 1963 1/

Prepared by the Market Quality Research Division
Agricultural Research Service 2/

INTRODUCTION

This report is a digest of recent literature pertaining to the biological and physical aspects of marketing apples. 3/ The economic phases of marketing are not included in this report; they are reviewed in "Apple Marketing--A Review of Economic Research, 1945-1960," ERS-140, by Alfred J. Burns, George R. Rockwell, Jr., and Elton Thigpen, published by the U. S. Department of Agriculture in October 1963. Literature pertaining to engineering and market facilities are also largely excluded from this report. A few references relating to costs, engineering, and market facilities are discussed when they have a direct relationship to the subject being reviewed.

This report was requested by the Marketing Research Committee of the National Apple Institute to assist the industry, research workers, and public agencies in planning apple marketing research.

1/ A few earlier citations that seemed pertinent for the sake of continuity are included.

2/ This review was prepared by the following staff members of the Market Quality Research Division:

Harvest maturity, by J. N. Yeatman.

Harvesting, handling, grading, and packing; waxes and skin coatings; shipping containers and consumer packaging; and film box liners and pallet covers, by R. E. Hardenburg.

Storage (general); preharvest effects on storage quality; precooling and temperature effects during storage; controlled-atmosphere storage; and volatiles and atmosphere purification in storage, by R. E. Anderson.

Ripening and composition, by P. H. Heinze.

Transportation, by W. H. Redit.

Terminal market handling and bruise control, by W. E. Tolle.

Market diseases, by L. P. McColloch and J. N. Yeatman.

Scald, by R. E. Hardenburg.

3/ Trade names as used in this publication are solely to provide specific information. Mention of a trade name does not constitute a guarantee or warranty and does not signify that the product is approved to the exclusion of other comparable products.

Maturity as defined by the United States Standards for Apples (85) means that the apples have reached the stage of growth which will insure the proper completion of the ripening process. [1/] Changes in the fruit after harvest are ripening changes, but such changes often occur on the tree and may accompany or follow the maturity changes.

Haller and Magness (26) distinguished several stages of maturity in apples as follows: Immaturity--Apples picked immature will soften somewhat and may turn yellow when ripened, but the flesh is likely to be tough, the taste sour, the flavor lacking or undesirable, or the storage quality poor because of susceptibility to storage scald, bitter pit, or other disorders associated with immaturity. Early maturity--Apples picked at early maturity ripen with only fair dessert quality for the variety, but are reasonably free from disorders associated with immaturity during storage. The beginning of this maturity period is the earliest time at which picking can begin with satisfactory results. Optimum maturity--Apples picked at optimum maturity can be stored with a minimum of storage disorders and ripened with maximum dessert quality for the variety and conditions of growth. Late maturity--Apples picked at late maturity are still satisfactory for picking, but they will be somewhat flat in flavor and may show a slight tendency to become mealy and to develop disorders associated with overmaturity. Overmaturity--When allowed to remain on the tree until overmature, apples may ripen quickly to a mealy condition, may be flat in taste, or may be subject to internal breakdown or decay during storage.

The following terms in the U. S. Standards for Apples (85) describe the varying degrees of firmness (or ripeness) of a mature apple: (Some ripening may occur while the fruit are still on the tree). "Hard" means apples with a tenacious flesh and starchy flavor; "firm" means apples with a tenacious flesh but which are becoming crisp with a slightly starchy flavor, except the Delicious variety; "firm ripe" means apples with crisp flesh except that the flesh of the apples of the Gano, Ben Davis, and Rome Beauty varieties may be slightly mealy; "ripe" means apples with mealy flesh and soon to become soft for the variety; and "overripe" means apples which are dead ripe, with flesh very mealy or soft, and past commercial utility.

In defining maturity as the condition of mature fruit, Lott (43) said that maturity has no stages or degrees.

Generally, the aspects of maturity take two forms, the physical and the chemical. These aspects have usually been investigated, with the prime objective of determining when apples should be picked to have optimum storage and dessert qualities.

In considering methods of determining maturity such tests as total soluble solids, total titratable acidity, starch content, firmness, juice volume, respiration, ground color, flesh color, days after full bloom, calendar date, ease of separation (abscission), size, and weight changes have been evaluated. Some of these tests have shown no promise in overall consideration but have been of value in specific locations where used and with certain varieties of apples. More promising tests have been implemented for more objectivity, such as firmness measurement, color, starch content, and respiration.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 15.

A discussion of the present status of the various indices of maturity as well as new techniques of maturity evaluation follows.

Physical Aspects

Size and Weight

Lott (42) showed that a decided change in the color of skin of Transparent and Duchess apples measured by reflectance spectrophotometry was accompanied by a rapid increase in size and weight of the fruit.

Lott (44) points out that there is rapid cell division in the early developmental stages of maturity terminating 3 to 4 weeks after bloom. During this time the cell walls are thin and cell enlargement is taking place. In midseason, cells cease to divide, cell walls become thicker, cells enlarge and intercellular spaces develop, and the cuticle thickens. Finally, with maturation, cell walls become thinner, cells continue to grow, and intercellular spaces increase.

Bain and Robertson (2) showed, at least with the Granny Smith apple variety, that as long as the fruit stayed on the tree cell enlargement continued and that after 205 days from full bloom, cell size and average weight of the fruit were still increasing.

Robertson and Turner (67) thought that marked changes in carbohydrate content of Granny Smith apples (dry weight increasing more rapidly than cell size) made dry weight studies unsuitable as a basis of expression of growth associated with cell enlargement. They thought fresh fruit weight was more suitable but was fraught with problems of sampling error.

Martin (51) pointed out that increase in size of Cox, Jonathan, and Sturmer apple varieties was accompanied by more rapid acid loss, starch conversion, and perhaps softening and slower accumulation of soluble solids. On the other hand, he said that as Cleopatra variety fruit increased in size acid was higher and starch loss lower. No explanation could be offered for the two conditions, but he states that it is probable that the Cox, Jonathan, and Sturmer varieties were growing faster than material could be transported. The lower acid concentration and soluble solids were due to dilution and earlier starch conversion from utilization of resources to meet growth needs. In Cleopatra, supplies were apparently adequate to keep pace with expansion.

While such variability is apparent and minimizes the value of size and weight as a means of differentiating maturity, Lusis (48) was able to show that specific weight determination of German apple varieties by hydrostatic method can be taken as a measure for determining the stage of maturation especially in fruit for storing.

West (89) showed graphically an increasing weight relationship with fruit ontogeny and a flattening of the growth curve as optimum maturity was approached. This study gave some credence to weight relationships of the apple as a guide to maturity.

Martin (51) also pointed out that the direct correlation of size with breakdown, deep scald, or Jonathan spot might be due to the direct relation of size and maturity factors shown for Cox and Jonathan as these disorders tend to increase with increasing maturity. This could not be the case for the direct relation of size and bitter pit in Cox and Sturmer varieties because bitter pit incidence decreases with maturity.

Ease of Separation

Smock (73) stated that ease of separation from the spur could only be classed as a "rough" or crude guide to maturity.

Poapst, Phillips, and Ward (63), believing that an association could be found between fruit abscission and decline of starch in fruit residual on the tree, assessed starch content empirically with the starch iodine index chart of Davis and Blair (13). No relationship was found however at that time, but an extension of the starch test proved to have some value.

Rollins and Mattus (68) stated that ease of separation from the spur was useful, but like so many other indices was not sufficiently dependable to be used alone.

Poapst, Ward, and Phillips (64) again in 1959 reported results of the timing of abscission in McIntosh apples in relation to starch disappearance. In this comprehensive report they suggest a formula for calculating the date of mean maturity which was considered to be the middle condition of abscission. They found that the index of maturity was directly proportional to starch analysis for any one season but did not extend between seasons. The relation of starch to abscission was seen best in the indexing of windfalls. Harvest drop tended to occur at a fixed date of mean maturity or fixed concentration of starch for a season. Generally, abscission was found to precede complete loss of starch in McIntosh. It appeared that the lead or lag in abscission was a function of temperature.

Poapst and coworkers concluded that there appears to be an association between the timing of the processes of abscission and decline of starch in McIntosh at harvest and that this association is affected considerably by prevailing seasonal temperatures. They state that an appreciation of these two points should permit more accurate assessment of the degree of maturity of McIntosh and also should increase acceptance of starch measurement as a harvest-time guide.

Days From Full Bloom

Haller and Smith (27) in a rather complete evaluation of maturity indices concluded that the elapsed time from full bloom to maturity was fairly constant for each variety under widely different cultural and climatic conditions and was the most reliable index to maturity. This is probably the most widely used guide for determining maturity of apples. It is usually used in conjunction with other indices and personal judgment. Van Doren (87) describes the formation and activities of the Delicious Maturity Committee of the Washington State Horticultural Association. He emphasizes the value of days from full bloom as an index of maturity but does not eliminate the other factors that help determine the optimum harvest maturity such as ground color, flesh color and flavor.

Smock (73) felt, however, that days from full bloom was too variable to be used as a measure of maturity for McIntosh apples.

Fisher and Smith (20) thought that the decision to harvest apples should be based upon a number of factors--days from full bloom setting the tentative date to start picking.

Crowe (11) relating previous work to Nova Scotia conditions established or suggested developmental periods (days from full bloom) for a number of varieties.

Comin and Ting (10) reported that Rome Beauty apples scalded severely when harvested before 160 days after bloom in Ohio and that the incidence dropped 20 to 80 percent when fruit were picked one week later. Optimum harvest in this case was as given by Haller and Magness (26).

Rollins and Mattus (68) considered one of the better guides to harvest at optimum maturity to be the number of days after full bloom. Full bloom in this case is taken as the day on which petals are dropping from the center blossoms. They suggested a schedule for a number of varieties grown in the Virginia apple region as to their requirements for days after full bloom for moderately bearing trees. Generally, their suggested dates for optimum maturity were 2 to 5 days later for Jonathan, Grimes Golden, Delicious, Golden Delicious, and Stayman than suggested by Haller and Magness (26). The number of days from full bloom to optimum maturity for York Imperial, Rome Beauty, and Winesap were 5 to 10 days earlier than Haller and Magness' suggestions. The differences in elapsed time suggested by these workers may have been due to date at which full bloom was set for the varieties as well as the specificity of the Rollins and Mattus data for the Virginia area, whereas Haller and Magness' results were based on a broader spectrum of locations.

Climatic Conditions

Temperature and other climatic conditions have often been considered to influence maturation. Indeed, some workers have put considerable emphasis on certain factors such as rainfall, mean temperatures, and solar radiation.

Ignatius and DeWitt (31) proposed that the size of an apple crop could be calculated before harvesttime by a regression equation having the following variants: (1) Difference in rainfall between two critical periods (July 12-August 10 and June 10-June 30) in the year preceding harvest; (2) the minimum temperature during blossoming in the year of harvest; and (3) the total number of hours of sunshine after blossoming during the period May 20-June 10.

Haller and Smith (27) reported that temperature apparently has less effect on the development and time of maturation of apples than might be expected. There was some indication that heavy rainfall or ample moisture, particularly late in the season, may delay the time at which fruit becomes resistant to storage scald and thus increase the period from bloom to maturity with scald-susceptible varieties.

Fisher and Smith (20) stated that picking date would probably have to be advanced with a light crop or exceptionally warm weather after bloom; conversely, that a heavy crop or cold weather after bloom was likely to delay date of picking.

Smock (74) reported that high soluble solids in McIntosh fruit at harvest were more strongly correlated with solar radiation during the later part of the growing season than during entire growing season. He also stated that a high degree of susceptibility to brown core in McIntosh was associated with low solar radiation and low mean temperature during the last 6 weeks of growing season. Susceptibility to scald seemed associated with high mean temperatures during the last 6 weeks of growing season for both McIntosh and Rhode Island varieties.

Tukey (83), while studying the effect of night temperatures on the growth of fruit bearing branches of McIntosh enclosed in heated chambers, found that night temperatures of approximately 81° F. appeared most favorable for enlargement of fruit within 4 days after petal fall, approximately 72°

from 4 to approximately 38 days after petal fall and approximately 65° from 38 to 70 days after petal fall. Higher and lower temperatures reduced rate of growth. Such effects might manifest themselves in date of harvest maturity.

Poapst, Ward, and Phillips (64) stated that the relationship between mean abscission and complete starch disappearance in attached McIntosh fruit is related to prevailing seasonal temperature.

The physiological heat unit method has been used to some advantage. Haller and Smith (27) computed heat units from the monthly mean temperatures at a number of locations and presented this information for five of the principal varieties of apples: Jonathan, Grimes Golden, Delicious, Golden Delicious, and Stayman Winesap. They indicate that not much reliance can be placed on heat unit summations.

Eggert (18) on the other hand demonstrated that a regression calculated on the basis of degree day summations from petal fall to 40 days after petal fall should give the most reliable prediction of maturity of McIntosh apples. Both the physiological heat units method and the daily mean minus a base temperature of 0° F. (degree days) were used to calculate heat units summation. A correlation coefficient of -0.959 was obtained between length of elapsed time (in days) from petal fall to harvest and the degree days accumulated at 40 days after petal fall.

LaBelle et al. (37) reported that heat unit accumulation and days after full bloom were equally effective. Their results would indicate that prediction of 1958 harvest maturity based on 1957 would have been a compromise between these two indices.

Aside from temperature, rainfall, and soil moisture effect on apple maturity, other factors such as elevation may play a part. Haller and Smith (27) showed that there was no evidence that elevation had any direct effect on the length of time from bloom to maturity. Damast (12) studied the effects of mountainous versus lowland areas on maturity and quality of apples. The same variety grown in high areas of Palestine was longer in shape, tending to become ribbed and ridged; the hypodermis was thicker, higher in dry matter, sugar, cellulose, acid and ash but lower in protein content; and rate of respiration was lower. He concluded that intensity and quality of light as well as temperature seemed to be the primary factors involved in these differences.

Firmness

Since Magness and Taylor (49) first described their fruit pressure tester it has been used by many workers on a number of different fruits. It has proven to be a reliable method of measuring maturity of pears and peaches but not apples.

Haller (25) pointed out in his review of pressure testers that they had not been found to form a reliable index to maturity of apples except to indicate when certain varieties were becoming soft and overmature for storage. They do, he said, constitute a fairly accurate guide to ripeness of apples during or after storage. Schomer and Olsen (69) developed an attachment, the Mechanical Thumb, for the Magness-Taylor pressure tester. It was found satisfactory for determining the firmness of unpeeled apples. Pressure readings were comparable to those obtained with the Magness-Taylor pressure tester. The bruises made at contact points were relatively small and inconspicuous, and the fruit need not be discarded after testing.

Lee and Oberle (41) compared the so-called "pea" penetrometer with the Magness-Taylor pressure tester obtaining a high correlation of 0.96 ± 0.015 standard error. The penetrometer blades shear a known volume of tissue and the instrument expresses values in pounds force per square inch. The penetrometer values decrease with advancing maturity to a point where a flattening off or no change in reading indicates optimum maturity.

Lee's data show that a prediction of a set penetrometer value for a given variety would not be applicable from season to season.

Caldwell, Culpepper, and Demaree (5) determined the relationship of different pressure test groups (firmness of raw product measured by Magness-Taylor pressure tester) with color, flavor, and particularly disintegration of frozen apple packs. Disintegration increased rapidly with decreasing firmness.

Pflug, Joffe, and Nicholas (61) constructed a mechanically driven pressure tester incorporating a force versus displacement recording system. With vertical placement and a controlled system, greater accuracy could be maintained and human variability diminished.

Nicholas (56) showed that firmness measurements of several materials, including apples, are different depending on the individual making the measurement. Comparisons of the variance of the force readings obtained by individuals using a fruit pressure tester with the variance obtained by a mechanical recording pressure tester show discrepancies depending on the product tested.

Decker et al. (15) modified the shear-press for electrical indicating and recording. Work curves for fruit and vegetable products could then be developed that would provide more complete information about the product.

Woodmansee, McClendon, and Somers (92) correlated pressure test readings of Stayman apples with three greatly different stages of maturity of freshly harvested fruit.

Wiley and Thompson (90) used the shear-press to good advantage on apples to predict canned apple slice firmness and wholeness. They found that readings within a 300- to 400-pound range gave slices of most ideal firmness and wholeness. Ideal firmness was found in early harvested apples which had ripened slightly in storage.

Shallenberger et al. (70) reported that as harvest date was delayed, color and flavor improved and texture became firmer in canned apple slices. The relationship between the alcohol insoluble solids to total solids ratio and the increasing firmness of slices with increasing blanch temperature suggests the basis for establishing a raw-apple objective index of slice firmness.

Mohsenin, Goehlich, and Tukey (55) found that a yield point and rupture point determined by a new compression tester were more definitive of force reference than the 1/4 inch line of the Magness-Taylor tester. They also found that as fruits mature, both the deformation curve and energy curve drop more rapidly than the stress curve during the harvest period. The compression tester seemed to be a better instrument for determining maturity and ripeness of apples, since several physical properties of the fruit can be measured and calculated at definite reference points.

Color

The color of apple fruit is often the principal criterion for acceptance by the consumer. The Federal grades assign considerable import to color, specifying that as high as 66 percent of the total surface area of the solid

red varieties shall be covered with a good shade of solid red characteristic of variety for the extra fancy grade; 40 percent for U. S. Fancy; and 25 percent for U. S. No. 1. The requirements for the striped partially red varieties are: 25 to 66 percent for extra fancy, 10 to 33 percent for U. S. Fancy, and from tinge to 25 percent for U. S. No. 1.

Lott (43) in his discussion of fruit maturation and ripening pointed out the very good use to which reflectance spectrophotometry could be put to characterize the color of yellow varieties of apples and showed how the Munsell color system offered a means of expression of the resultant color data from spectrophotometry.

In Lott's work (42) reflectance curves were drawn for Transparent and Duchess varieties showing differences with advancing maturity great enough to indicate the possibility of establishing maturity standards on the basis of ground color.

Many workers (20, 10, 27, 51, 52, 84, 78, 80, 66, 42) have shown the value of ground color as an index of maturity. Stoll (78) developed a chart for the Jonathan variety varying from light green to yellow, similar to the USDA ground color chart (50) but including one additional color.

Smock (73) showed that amount of surface or red color on McIntosh apples was a poor index of maturity, but that ground color was one of the best indices. While there was some range from year to year, he thought that a ground color chart developed by F. W. Southwick for McIntosh improved this index.

Porritt and Fisher (66) evaluated ground color of Golden Delicious by comparison of samples with Ridgeway color plates.

Dayton (14) studying the distribution of red color in the skin of apples used the Nickerson Color Fan (57) to make visual comparisons with the color in individual cells of the epidermal and hypodermal layers of many varieties of apples. He found an apparent range in color from Munsell renotation 10 RP 3/10, deep purplish red, to 2.5 R 9/3, pale pink, including all varieties under study.

Aubert (1) reported a good relation between fruit quality and time of picking utilizing color plates of the International Color Code to assign some objectivity to visual comparison data.

Lott (46) describes the development of his color standards for Golden Delicious apples which became a part of Illinois State grades for maturity in July 1959. These standards were developed from analysis of spectral reflectance curves of a large number of fruit evaluated over several years at various stages of maturation. Lott (47) reports that because of allowable variability in color and associated quality constituents, the apple grades widely used for packing Golden Delicious are unreliable as indices of degree of quality. He suggests that the use of color standards, such as the Illinois maturity standards, would provide standardization within practical limits and the elimination of low quality apples from packs thus making each grade designation an index of the degree of quality within the package.

Color measurement of apples has been made objective by the application of reflectance colorimeters and more recently by the light transmittance technique of measurement of the intact fruit.

Miller (54) in a rather comprehensive study of the relation of plastid pigments to color in Transparent and Golden Delicious varieties described a method whereby percent reflectance measurement of apple skin at 676 nm could be converted into weight of chlorophyll per unit area by means of standard curve prepared for the particular variety. He suggested that the standard curves might be the basis for maturity standards. In his work heavy

applications of complete fertilizers did not change significantly the concentration of chlorophyll in the skin of fruit but concentration of total carotenoids was significantly increased with such fertilization.

Desrosier, Billerbeck, and Tukey (16) developed a reflectometer using appropriate filter-photocell-light source combinations and a sample rotator, which showed a good relationship between external color measurement and the U. S. grades for apples. The so-called Purdue color ratio meter viewed the entire surface of the apple except for small areas at the stem and calyx ends.

Francis (21) on the other hand used a color and color difference meter, long used in the paint and varnish field of color evaluation, to study skin color in apple varieties. Tests with the Photovolt instrument were not as conclusive as the Hunter Color and Color Difference Meter (CDM). His results indicated fair to good correlation of visual ratings of fruit with Hunter Rd, a, b, and $\tan^{-1}$ a/b ratio values. A sample rotator used with the colorimeter was considered to integrate the variable colors over the surface of the apple sample, but such measurement is open to question due to the constant changing of geometry in the color measuring system as the fruit revolves over the exposure head of the instrument.

Wiley and Thompson (90) used the Hunter CDM to relate raw flesh color to processed apple slices. They concluded that approximately 45 percent of the overall grade for finished product was accounted for by color; factors of wholeness and firmness (47.5%) and flavor (7.5%) accounted for the remainder of the grade.

Carrying reflectance measurement a step further brought the development of the automatic apple sorter which has been used in the Pacific Northwest. Larsen (38) reports an objective color sorting system whereby fruit surface is scanned by eight lights, the light from which is reflected upward to be characterized by photoelectric cells as to extent of redness or lack of redness. The instrument sorts intact fruit into extra fancy, fancy, and No. 1 grade. The rapid rate of speed (1260 fruit per minute) enables handling of large quantities of fruit which would require many people to sort who would be subject to fatigue and variation in color memory. With change of filters the instrument will sort red and yellow apple varieties equally well.

Boynton, Compton, and Fisher (4) showed that leaf chlorophyll level 2.0 to 2.2 mg/65 cm^2 surface (one side) corresponded to color standard #4 specified by the New York Agricultural Experiment Station. Such a color designation was associated with a nitrogen status of spring fertilized trees high enough for maximum yield. A greater chlorophyll content might indicate nitrogen status above that necessary for maximum yield with unnecessary reduction in fruit color at harvest.

Shear and Horsfall (71) also used the New York color standards for leaf chlorophyll and suggested that for standard #1 the percentage nitrogen level be raised from 1.5 to 1.7; color standard #2 from 1.7 to 2.0; color standard #3 from 1.9 to 2.3; color standard #4 from 2.1 to 2.7; and color standard #5 from 2.3 to 3.1. These standards were for York and Stayman apples.

Clijsters, Wolvertz, and Sironval (7) suggest a procedure for the extraction of chlorophyll as a guide to the harvest of Jonathan apples to avoid rot in storage. They found that fruit that contained less than 30 micrograms chlorophyll per 10 cm^2 of skin would not store well regardless of red pigment development.

Norris (58) described the development and application of new light transmittance instruments to measure internal pigment characteristics of intact agricultural commodities. While reflectance measurement permitted evaluation of surface appearance of commodities, it did not permit evaluations of interior characteristics of a sample. In many cases interior characteristics provide information about quality, maturity, and presence of certain defects that is impossible in reflectance measurements. With the system developed by Norris, chlorophyll content of the intact apple fruit could be indicated.

Norris et al. (59) described the technique of rapid estimation of chlorophyll in apples and presented data to show the relationship of total extractable chlorophyll to instrument estimation in the intact fruit.

Birth (3) describes an instrument designed to provide innumerable selection of wavelengths for detection of various pigments in the intact fruit. Such an instrument was the forerunner of the new ratio spectrophotometers which enable rapid sorting of product for internal pigmentation or certain defects within a product. Birth's dual monochromator spectrophotometer was applied to apples. He states "that during a test with apples the average time per fruit was 20 seconds with one person handling the entire operation. With mechanical handling of the fruit a speed of approximately one fruit per second would be the maximum theoretical speed that could be obtained with the instrument." The principal deterrent to very rapid sorting of apples is not the electronics involved in the instrument but the care with which the fruit must be handled to prevent bruising.

In the yellow skin varieties of apples, not masked by anthocyanin pigments, chlorophyll disappearance internally is directly correlated with chlorophyll disappearance externally. Sorting for the extent of green pigment internally by light transmittance technique therefore would also provide a good visual sort for surface color.

Workman (93) reported that Grimes Golden did not develop acceptable color or edible quality on the tree, whereas Golden Delicious did. He suggested a direct relationship existed between the time required to attain the climacteric peak and the time to develop an acceptable color.

Chemical Aspects

Starch Content

The relation of starch content of fresh apples to maturity has been extensively evaluated by research workers. Some have found it to offer considerable promise as an index of maturity, while others have had little success with it.

Griffiths and Potter (24) presented procedures for determining starch content of apples indicating a number of fractional components of the total starch content of the apple.

Kidd et al. (34) pointed out that it was unlikely that the process of synthesis or condensation of starch proceeding in the tree should cease instantaneously when the fruit is picked. His quantity/time curves for starch loss in apples were interpreted as follows: (1) the process of starch synthesis in progress on the tree continues for a short time, 1 or 2 days after harvesting, and then rapidly falls to zero; (2) during this time and subsequently, the process of degradation of starch in the apple is proceeding at a rate proportional

either to amount of starch present or to the surface area of the starch grain; (3) degradation and synthesis of starch may be independent and simultaneously occurring processes.

Lott (43) showed with Transparent and Duchess apples that as maturity progressed, there was an initial increase in starch content followed by a decrease which was most pronounced in the week preceding optimum maturity.

Lott (44) also pointed out that there was seldom if ever an amount of starch more than about one-tenth as great as the amount of sugars in apples. He said that this fact points to the fallacy of the statement that apples can be picked when still immature and that starch will change to sugar during ripening; there is not enough starch present to materially increase sugar content.

Martin (51) observed that starch conversion proceeded faster in larger fruit of the Cox, Jonathan, and Sturmer apple varieties than in Cleopatra variety where larger fruits were characterized by lower starch loss. He pointed out that it was probable in Cox, Jonathan, and Sturmer that the larger fruit were growing faster than material could be transported, and the earlier starch conversion was due to utilization of reserves to meet growth needs. In Cleopatra, supplies were apparently more than adequate to keep pace with expansion.

Martin (51) offered a simple maturity pattern for the Cox apple variety. He found that the amount of starch conversion was based on the proportion of unstained tissue in an equatorial section of apple stained with iodine-potassium iodine solution.

Continuing his work on between tree variation due to cropping factors, Martin (52) found that up to a late stage of maturity, light crop fruit of the Cox and Cleopatra varieties had larger diameter, higher acidity, earlier color change, and later starch conversion than heavy crop fruit.

Poapst, Phillips, and Ward (63), working with McIntosh variety, determined that the starch levels in fruit varied appreciably from season to season and postulated that maturity may be related to anatomical location of the retreating starch granules rather than actual amount.

Ward (88) compared two methods of measuring the rate of disappearance of starch in estimating stage of maturity and correct time for harvesting: (1) the comparison of the starch-iodine pattern on cut McIntosh apples with standard color charts and (2) the measure of starch-iodine color in perchloric acid extract. He showed a straight line relationship by perchloric acid procedure with starch disappearance at intervals through August and September for 3 years. It was not possible to determine any specific content of starch that would indicate optimum maturity.

Carter and Neubert (6) described a rapid method of starch determination using perchloric acid-iodine-starch reaction for Delicious apples. Their method involved fractional transmittance measurement at 620 nm of the starch-iodine reaction using an Evelyn colorimeter.

Treccani (81) concluded that none of the various indices of maturity can be considered absolute for Stayman Winesap although the iodine-potassium-iodine test for starch was most constant and most indicative.

Poapst (62) revealed that starch changes in McIntosh and natural drop were closely related in the dimension of time. He observed that complete dissolution of starch preceded drop when prevailing temperatures averaged 49° F. or less. Drop preceded starch loss at the rate of 1 day per every degree difference in average temperature over 49° F. Conditions of mean drop occurred at a starch index as low as 6 during warm seasons and as high as 7.2 during cool seasons. He said that for each season there is a fixed concentration of starch at which McIntosh apples drop.

Later, in 1959, Poapst, Ward, and Phillips (64) reported more complete findings in which they stated that of all the criteria of maturation which they had tried, including ground color, blush, acidity, soluble solids, firmness, respiration, or peroxidase activity, the use of the starch patterns described by Davis and Blair (13) was the most satisfactory. They suggested a formula for calculating date of mean maturity which they considered the middle condition of abscission.

Their relationship between index and starch pattern charts revealed an inherent error in the design of the Blair and Davis maturity chart in that extrapolated data failed to reach an index 9 and this bias varied from year to year. The reason for the difficulty was said to be embodied in the chart in that early changes represent major losses in starch content and later changes represent minor losses.

Respiration

One of the indices of the physiological and chemical changes in the apple is provided by intensity of respiration, as indicated by the rate of production of carbon dioxide.

West (89) reported a respiratory curve of the life of a Bramley Seedling apple. While fruit are on the tree, the rate of respiration drops from a maximum high in the stage of cell multiplication through a low period during cell enlargement. At harvest the rate of respiration rises again with the onset of the climacteric, falling off during senescence with a final quick rise at the death of the apple.

The height of any climacteric peak seems to vary with the picking date for different varieties. Smock and Gross (75) reported that late pickings of a given variety often had a higher climacteric peak during storage than early pickings. Kidd and West (33) found that this climacteric could also occur on the tree.

Hulme (29), in developing the ratio of rate of respiration to protein content, R/P, showed that subsequent to about 60 days from petal fall until the onset of the respiration climacteric, the rate of respiration of an apple on the tree is proportional to its content of protein. He stated that with the less developed apples the R/P ratio appeared to decrease from a relatively high value a few days after petal fall. Also, the mature preclimacteric apples showed an approximately constant R/P for a given variety, at least when cultural practices were not very different. Hulme suggested that the R/P ratio has a value characteristic of a variety and that the value tends to be higher for the dessert varieties rather than those for culinary use.

Robertson and Turner (67) reported changes in respiration in Granny Smith apples following varying days from full bloom.

Krotkov, Wilson, and Street (36), assigning less credence to rate of respiration as an index of maturity, suggested that pH of the juice of an apple might be a better indicator of the ontogenetic stage of the apple fruit than its respiration rate, carbohydrate content, or acid content.

Hulme (30), working with Cox's Orange Pippin, developed the theory that the difference in time between the onset of the respiration climacteric in harvested fruit held at 12° C. (53.6° F.) and at 15° C. (59° F.) varied from the date of picking fruit over a period a few weeks before to a few weeks after the commercial harvest date. This "time gap" had a minimal value which could vary from season to season. He suggested, however, that this "point of minimal

gap" reflected a definite physiological state of the fruit, which could prove to be a guide to "absolute" maturity in relation to picking for maximum storage life. He found that the "point minimal gap" occurred earliest in the season with earliest date of petal fall and latest in season with latest date of petal fall.

Ting (80) reported that, in general, as Rome Beauty apples developed on the tree during the period between 140 days (1st pick) and 175 days after full bloom (last pick of 6), respiration rate increased slowly, ground color values, reducing sugars, and nonreducing sugars increased, and total acidity, alcohol insoluble solids, and firmness of fruit decreased.

Wilkinson (91) described a simple method for following the climacteric in apples. His procedure depended on measuring the gas conditions in a closed system. He found that production of CO_2 or ethylene or decrease in O_2 could be used to indicate state of fruit maturity. Of the three he concluded that the measure of O_2 with the Beckman Oxygen meter was probably the simplest method.

Martin (52), working with light and heavy crop trees picked at successive maturities, showed that although other criteria of maturation, such as diameter, acidity, color change, etc., showed significant differences, the respiration per unit fresh weight of fruit was the same for different crop levels.

Sullivan and Enzie (79), trying a technique of correlating expressible juice of composite apple samples with various other criteria of maturity, found a direct correlation with rate of respiration. They found that at harvest and after being stored at 35° F. large Richared and Jonared apples had greater respiration rate and higher expressible juice content than small ones.

(See also section on Ripening and Composition for a discussion of relation of respiration to maturity and ripening.)

Acidity and Soluble Solids Determination

Determination of total acid, pH and soluble solids in apples has been found valuable in assessing stage of maturation (43, 10, 44, 51, 53, 94, 92, 46, 84, 80).

Martin (53) noted that acid concentration declined continuously during maturation. There appeared to be a relation between firmness and acid level.

Wiley and Thompson (90) pointed out that early harvested apples exhibited highest amount of total acid and water soluble pectic constituents. They found a 0.80 correlation coefficient between shear press reading on raw apple slices when harvested and when removed from storage and total pectins of Stayman, York and Jonathan varieties. Of the single tests, titratable acidity, shear press, soluble solids, and soluble solids/acid ratio appeared to be most important. They found that combinations of these factors gave the best estimate of overall grade.

LaBelle et al. (37) found a high correlation between soluble solids/acid ratio and heat unit accumulation in Rhode Island Greening and Baldwin apple varieties. The soluble solids/acid ratio changed rapidly prior to and at harvest and had a direct bearing on quality of applesauce.

Sullivan and Enzie (79) found that expressible juice was directly correlated with respiration rate and percent soluble solids of Richared and Jonared varieties.

Robertson and Turner (67) present the relationship of total organic acid, and malic and citric acids with varying days from full bloom for Granny Smith apple.

Krotkov, Wilson, and Street (36) showed that the various stages of acid metabolism of McIntosh grown in Canada correspond chronologically very closely with those of carbohydrate content and with respiration. They explained that during the first 4 to 6 weeks after petal fall the pH of raw apple juice decreases rapidly. It reached a value of 2.8 then slowly rose following a straight line for the rest of the ontogeny. They postulated that on account of this regularity, once the pH of juice had begun to increase, its magnitude represented a better indicator of stage of maturation than its respiration rate or either carbohydrate or acid content. Malic acid after reaching a level of about 80 percent of the total organic acid content of the fruit remained at that level for the rest of the ontogeny. They observed no disappearance of organic acids during the climacteric rise in the sugar content of fruits and no accumulation in the immediate postclimacteric period when large amounts of sugars disappear. They concluded that the variations in sugars are not brought about by their appearance from or disappearance into organic acids.

Comin and Sullivan (9) defined the index number as the ratio of the quantity of dissociated hydrogen to the quantity of displaceable hydrogen determined on a per unit displaceable hydrogen basis by dividing the gram moles of ionic hydrogen per liter calculated from the pH by the milliequivalents of hydrogen per liter (calculated from titration). Their work indicates that apples produced on trees in favorable nutritional balance will be higher in active hydrogen and tend to keep better in storage.

Comin and Sullivan (8) stated that the significance of the dissociation of acids index is based on the assumption that pectin, sugar, and acid contents at any time in the life history of a fruit are the resultant of certain complex equilibria which appear to be controlled, not by the content of any one constituent but rather by the degree of dissociation of the acid produced. They showed that the index number of Rome Beauty apples rose to a maximum occurring close to 167 days after full bloom. Most of their data showed a decided and consistent rise in index number starting close to 153 days from full bloom reported as the fore part of the optimum maturity range (155 days) for this variety. They concluded that actual physiological maturity can be measured closer by index number than by ground color for Rome Beauty apples.

Eaves and Leefe (17), in reporting a rapid technique for measuring titratable acidity, found no significant difference between amount of acid lost from apples picked at different dates and stored at 34° F. for 5 months. Acid was positively correlated with potassium of leaves and less positively correlated with N/K ratio in leaves.

The results of Eggert, Murphy, and Johnson (19) showed no relationship with McIntosh between palatability findings and pressure tests, soluble solids, total acid, and soluble solids/acid ratio.

Pectinic and Cellulosic Changes

The dissolution of pectin and cellulosic changes in apples with stage of maturation has been studied extensively and found to offer value in predicting when to pick the fruit.

Pollard and Kieser (65) described experiments which showed that many of the commoner varieties of apple contain appreciable amounts of pectase, the level of activity varying according to variety and stage of maturity.

Lawrence and Groves (40) pointed out that available methods for determination of pectin in apples are not particularly satisfactory for routine use. They presented a modified calcium pectate method and a new photometric method based on the absorption at 295 nm of a pectin sample heated in a boiling water bath with nine volumes of 84 percent sulfuric acid.

Gee, Reeve, and McCready (22) introduced a new direct method for following the esterification of pectic substances in fruits at different stages of their development. They showed that the degree of esterification increased to nearly 100 percent with the onset of optimum maturity but decreased markedly as both Gravenstein and Golden Delicious apple varieties became overmature and softer.

Griffin and Kertesz (23) after a 5-year study with Webster apple variety found no conclusive evidence that protopectinase and pectin - polygalacturonase (pectinase) actually occur in the apple. Their results indicated that during maturation and softening of apples the tensile strength of the tissue and proportion of total pectic constituents decrease and the proportion of water-soluble pectic materials increases. They concluded that while it appears that both protopectinase and polygalacturonase are absent in apples, the functions attributed to both enzymes may be performed by nonenzymatic agents.

Woodmansee, McClendon, and Somers (92) found in the Stayman variety a significant decrease in total pectin (on a fresh weight basis) from the unripe to overripe stage while for "soluble" pectins, crude fiber, and protein no consistent trends could be observed. A characterization of total and "soluble" pectins showed that ripening of fruits was associated with decrease in apparent equivalent weight and in degree of esterification.

Wiley and Thompson (90) found the pectic contents of raw apples of various maturity levels were significantly different, with early maturity apples exhibiting the highest amounts of total, acid soluble, and water soluble pectic constituents. Total pectins were more closely related to raw apple texture, and acid soluble pectins were more closely related to firmness and wholeness of canned slices.

Kertesz, Eucare, and Fox (32), studying apple cellulose, found that apples that were originally firm softened more in storage than those that were less firm. Their results indicated that cellulose concentration is a factor in apple firmness at time of picking but that neither changes in amount nor in quality of the cellulose are involved in softening that occurs in storage.

Truscott and Wickson (82) and Simpson (72) found considerable changes in viscosity of fruit juice measured at intervals before commercial harvest. They suggested juice viscosity as a useful indicator of proper picking maturity. Working with Duchess variety, Truscott and Wickson observed that changes in viscosity of harvested fruit ripened in the laboratory essentially paralleled those in similar fruit maturing on the tree.

(See also section on Ripening and Composition.)

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HARVESTING, HANDLING, GRADING, AND PACKING 1/

Harvesting

If fruit is to reach the consumer in good condition, great care must be taken at each step in handling from orchard to retailing. Harvesting of apples must be carefully supervised or fruit may be severely damaged before it even reaches the packing house. Many bulletins have described the need for improved handling, but bruising and other mechanical damage continue to be a leading cause of waste in marketing. Many lots of apples are handled as many as 30 times from picking to consumer.

Setting ladders against the tree is one of the first operations where damage may occur. Excessive speed in picking is another cause of injury according to Ellenwood (25). 2/ Men who pick the most boxes often bruise the most apples, although this does not mean that fast workers are always rough. Good picking and handling practices have been described by Fisher and Smith (29), Allen (3), Woodward (74), Blanpied, Markwardt, and Ludington (11), Dominick and Stanton (23) and Chapman (20). Workers should pick as much fruit as possible while standing on the ground before they set a ladder. Then they should pick as they move up a ladder. Rules for ladder safety have been listed by Blanpied et al. (10).

Picking Containers

There is no general agreement of the best picking container. Fisher and Smith (29) found that metal picking buckets with canvas bottoms caused less fruit damage than canvas picking bags. Woodward (74) found that care exercised in picking and dumping fruit into boxes was more important than the type of picking container. For easily damaged varieties, such as McIntosh and Golden

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1/ See also section on Bruise Control.
2/ Underscored numbers in parentheses refer to Literature Cited, p. 28.

Delicious, some growers are using 1/2-bushel fiberboard picking boxes with snap-on shoulder straps (6). This is an excellent procedure for minimizing bruising as there is no dumping from picking bags. The fiberboard picking boxes are transported on flat-bed trailers or on special pallets. As with any field container, the fiberboard picking boxes must not be overfilled to avoid damage from stacking.

One study showed that pads in the bottom of wooden field crates reduced bruising (74).

Palletized Handling and Bulk Bins in the Orchard

Palletized handling of field crates in the orchard has become a labor saver (17, 73). Fisher and Smith (29) found 41 bruises per 100 apples hauled from the orchard in individual field boxes and only 8 bruises per 100 apples when field boxes were on pallets. Handling on pallets is often not adapted to small storage rooms with low ceilings and supporting pillars (4). Bruising can be worse with pallets than without, if the forklift or tractor operator is rough. Lotter (47) concluded that supervision and condition of roads were important factors affecting damage of apples.

Use of bulk boxes or pallet bins has become standard practice for handling apples in some regions. Many workers have studied this development, which originated in New Zealand in 1953 (1, 2, 6, 8, 9, 10, 21, 24, 32, 34, 38, 41, 42, 45, 46, 48, 50, 54, 55, 57, 64, 68, 70). One of the contributing factors to the shift to bulk boxes in the United States has been the change from standard wooden boxes for shipping to corrugated boxes (38).

The popularity of bulk boxes for harvesting, for transport to packinghouses, and for storing apples is primarily due to savings in picking and handling costs, plus better utilization of space (24). When bulk boxes are used, fewer men are required for setting out empty containers in the orchard, for loading and unloading trailers, and for filling storages (2).

The boxes must be rigidly constructed. If strongly built, they are handled more easily than palletized boxes (24, 64). Another advantage is that bulk boxes full of fruit are too heavy to be picked up manually and dropped or carelessly handled by workers. It is relatively easy to insure careful handling by forklift truck operators (2). Blanpied, Markwardt, and Ludington (11) have listed many of the advantages and disadvantages of bulk box usage by apple growers. Orchard topography must be such that forklift tractors can operate satisfactorily to move the bulk boxes. Gaston and Levin (32) stated that growers who produce 8,000 or more crates of apples will find investment in forklift equipment feasible.

Bulk boxes are useful in handling fresh-market apples, processing apples, windfalls, and cull apples. The effect of bulk boxes on fruit quality is still being tested, but they have proven satisfactory for both handling and storage (1, 2, 11, 32, 34). McBirney and van Doren (48) reported that apples harvested in 24-bushel bins had slightly fewer bruises than those harvested in regular wooden field crates. Bruising increased with the depth of the bins and was greatest in the bottom layers. They recommended a maximum bin depth of 24 to 26 inches if apples are to be stored in bulk containers. Spencer (68) found less bruising of Bramley's Seedling apples when bulk boxes were used for harvesting instead of bushel boxes. A fruit depth of 21 inches is probably the maximum for safe handling of this variety (64, 68).

Blanpied, Ludington, and Potter (9) found no difference in bruising between field crates and bulk boxes during handling of McIntosh apples, if the bulk boxes were only 20 inches deep. With 30-inch deep bulk boxes there were 38 percent more bruised McIntosh than with field crates. O'Brien (54) concluded that a 24-inch inside depth was best to minimize transit damage of fruit and for stacking 7 boxes high. Johnson (42) and Hall and Mellor (34) have described bulk handling of apples in Australia. Bulk boxes have been adapted for export use.

Handling Equipment in the Packinghouse

Continued expansion in the use of new mechanical equipment for handling apples is noteworthy. The advantages and disadvantages of mechanical versus manual handling were listed by Blanpied, Markwardt, and Ludington (11). It is common for one man with mechanical equipment to do the work of three or four men handling fruit manually. Fruit can be brought into the packinghouse or directly into storage faster with mechanical equipment, and usually it is in better condition after storage. Smith, Wright, and Adams (63) have pointed out that any bruising opens lenticels providing an entrance for decay-producing spores. Scott (62) in Ohio found that two-thirds of the Delicious and four-fifths of the Stayman apples were bruised to some degree on arrival at the packing shed.

Carlsen, Hunter, Duerden, and Herrick (16) found that modern mechanized equipment can move fruit more rapidly after harvest and place it in refrigerated storage sooner. Considerable storage life was often lost from fruit by older, slower methods of loading, receiving, and stowing fruit. Mechanical equipment makes it easier to move fruit out of the sun, wind, or rain and into storage. Various types of materials-handling equipment for apple packinghouses have been evaluated by numerous researchers (9, 12, 13, 15, 16, 26, 28, 32, 33, 37, 38, 41, 42, 43, 44, 45, 46, 50, 51, 53, 56, 57, 66, 69). The volume of fruit to be handled is an important consideration in determining whether such equipment would be economical (67). Levin and Gaston (46) listed and described many pieces of mechanical equipment, such as pallets, lifts, dumpers, and conveyors for handling deciduous fruits. The use of forklifts not only reduces the number of individual handlings but eliminates many of the damaging jolts and drops to which filled crates are often subjected.

Dumping apples from field containers onto the grading and packing line is a source of much potential damage (11). Evans and Marsh (26) found that hand dumping increased bruising 27 to 50 percent if done carelessly. Modern mechanical drum dumpers caused only 2 to 8 percent bruising. A simple hand-operated mechanical aid for dumping field crates was developed by Levin and Gaston (43). This dumper took most of the lift out of the job and a padded hinged cover regulated the flow of fruit. Dumping onto belts causes less damage than dumping into a bin (11). Blanpied, Markwardt, and Ludington (11) state that automatic bushel-box dumpers, washers, driers, and automatic box fillers frequently cause more damage than the equipment used for sorting, sizing, and accumulating.

Several reports have described the use of bulk-box dumpers (9, 10, 33, 45, 50, 57). Mechan and Fisher (50) tested 25-bushel bulk boxes having a depth of 24 inches. McIntosh apples dumped from these bulk boxes suffered less bruising and less stem punctures than dumping from field crates. Damage in dumping obviously is closely associated with type of equipment used, as well as

the care in its use. Levin and Gaston (45) found that a mechanically tilted bulk-box dumper caused 40 to 50 percent less bruising than hand dumping of fruit in field crates. Eaton (24) in England reported that dumping by mechanically inverting bulk boxes using a false lid caused excessive bruising. Endgate or submersion dumping caused less damage. Eaton stressed that whatever the layout adopted for dumping fruit, it should be designed to allow one operator to do all the emptying without the need for servicing by forklift trucks except at hourly intervals. Sammet (60) and Sammet and Davis (61) in California and Wilking (72) in Germany compared different types of equipment for handling and dumping incoming fruit in bulk boxes.

Some bulk boxes are equipped with hinged endgates. Blanpied et al (9) found that McIntosh in bulk boxes can be dumped through endgates satisfactorily if the boxes are only 20 inches deep. They concluded that water submersion dumping of bulk boxes 24 inches deep causes fewer stem punctures than endgate dumping. Pflug and Dewey (57) tested two types of bulk-box dumpers on McIntosh and Golden Delicious apples. These soft-fleshed varieties were injured by tilt-type dumpers that gradually invert the bulk box. But submerging the bulk boxes in water and allowing flotation unloading caused only a small fraction of the bruising that occurred with tilting-type dumpers.

Brushers are widely used to remove dust and spray materials to improve appearance. Some types do not operate effectively on wet fruit (33). More apples for the fresh market are being washed in recent years, often by passing them under a series of water sprays and brushes. Where residue removal is a special problem, techniques for removing the residues are available (4). However, Haller and Carter (35) and Walker (71) found that very little of the DDT residue could be removed from apples with various chemical washing treatments.

Matthee and Ginsburg (49) stressed the importance of packinghouse sanitation to keep the spore load low and minimize the chance for inoculating fruit. Field boxes and equipment can be cleaned with a 0.25 percent calcium hypochlorite solution or by 2 minutes exposure to steam. Storage rooms can be fumigated with a mixture of 85-percent carbon dioxide and 15-percent ethylene oxide.

Ellenwood (25) pointed out that grading is often a serious source of bruising, sometimes more serious than picking and transporting. Gaston and Levin (31) found that a mobile grader for use in the orchard was particularly useful where fruit is stored orchard-run. With this mobile grader, fruit is not dumped into field crates from picking bags, but is dumped directly on the grader. This means less handling and less bruising.

Crowding on grading and sizing equipment and excessive speed are common causes of bruising (7, 11, 22, 25, 26, 51, 52). Long drops and poorly padded equipment also contribute to bruising. Evans and Marsh (26, 27) reported that elevator chains and sorting rollers with slower speeds and less drop from elevator rollers, plus use of cloth brakes, reduced bruising. Felt or sponge rubber covered rollers helped in reducing injury. Canvas aprons and sponge rubber padding in appropriate places are useful. Evans and Marsh (26) stated that the amount of damage which occurs in packinghouses varies more with management and supervision than it does with the particular type of machinery. Machinery adjustments and personnel training are essential. Stoll (69) described various grading and sizing equipment in use in Europe.

Merchant (51) studied two different types of packing lines for McIntosh apples. Using manual dumping, chain eliminators, wooden sorting rolls, chain sizers, and 2-way belt accumulators, there was 47 percent slight bruising and 3 percent severe bruising. Using mechanical dumpers, chain and belt eliminators, rubber-covered sorting rolls, cup sizers, and 2-way belt accumulators,

there was only 16 percent slight bruising and no severe bruising. Hunter, Kafer, and Meyer (40) developed a float-roll sorting table that allowed about 17 percent more fruit to be sorted per hour than a reverse-roll table. Fruit could be seen more completely as apples were not crowded on the table, and the speed of forward motion of fruit was adjustable. They found no more bruising of Delicious apples from use of a float-roll table than from a reverse-roll table.

Burt (14) developed a packing line for McIntosh which utilized a drum dumper, sorting table, brusher, eliminator, sizer, and return-flow belt. It also employed an automatic box filler for jumble filling of utility grade fruit. This packing line allowed McIntosh apples to be packed mechanically at a lower labor cost with no increase in fruit injury.

Metz (52) found that supervision of grading and packing operations was often inadequate.

Carlsen and Herrick (19) described an automatic box filler that virtually eliminates labor costs in "loose filling" wood or corrugated containers. It uniformly filled 3 to 4 boxes of apples per minute. This was done gently with less danger of bruising than with most manual methods of box filling.

Moving Into Storage

Following grading and packing, fruit should be moved promptly into storage. Delayed storage is usually harmful, as each day at 70° F. reduces the storage life at 32° by a week (29, 65). Rapid cooling to remove field heat is desirable for most varieties (5, 34, 58, 59). Details of storage construction, arrangement, refrigeration equipment, and temperature and humidity requirements are described in numerous reports (5, 30, 36, 39, 58, 59, 65). In 1963, Heffernan (36) published plans for a packing line, a receiving area, a 140,000-bushel conventional storage, and for eight controlled-atmosphere rooms totaling 100,000-bushel capacity.

A high relative humidity in storage is essential if loss of moisture from fruit is to be minimized. Rostos (59) reported that weight losses average 1/2 to 1 percent per month in refrigerated storage. It is also well established that dry boxes and packing materials alone may absorb a pound or more of moisture per package (5). Sometimes storage crates are moistened before use in storage and sometimes moisture is added to the rooms to prevent fruit shriveling. The storage of apples in both air and controlled atmospheres is covered in greater detail in a separate section.

Use of pallet bins or bulk boxes in storage will conserve space. McBirney and van Doren (48), Herrick, McBirney, and Carlsen (38) and Patchen and Sainsbury (55) calculated that a cold storage can hold about 20 percent more fruit if bulk boxes are used instead of individual crates. With more fruit in storage, it must be remembered that more cooling capacity is needed (34, 55, 64).

Some types of bulk boxes cool fruit slightly slower than field crates, but not prohibitively. In general, apples stored in pallet boxes cool as well as or better than those stored in wooden boxes on pallets (21, 34, 38, 54, 55, 64). Patchen and Sainsbury (55), and Herrick, McBirney and Carlsen (38) evaluated many kinds of commercial and experimental bulk boxes. O'Brien (54) suggested that a 47-inch-square bulk box with 24-inch depth should have about 100 square inches of opening in the sides or bottom to provide adequate ventilation for good cooling in storage. Where air circulation is from ceiling to floor,

Smith and Roach (64) found that a minimum of 4 to 6 percent of the bottom surface of bulk boxes should be slotted to provide sufficient ventilation. Corrugated liners in bulk boxes retarded cooling even though they were provided with the same ventilation space as unlined boxes (55).

Hall and Mellor (34) found that with 10 percent of the bin bottom suitably ventilated and the whole bin freely exposed, initial cooling was as high as 4 degrees F. per hour. Rates of cooling of better than 2.5 degrees F. per hour were obtained with bins stacked three deep. With deeper stacking, cooling rate progressively decreases. Others have pointed out the importance of good spacing for cooling of bulk boxes (11, 21, 55). They should be 6 inches away from all walls; 5 inches should be allowed between rows; and pallet openings should all be in the same direction in storage and parallel to the direction of airflow.

Many workers have enumerated various construction details for bulk boxes which would add strength, minimize friction or bruise damage, or improve the cooling characteristics of these containers for apples (8, 9, 10, 24, 34, 38, 42, 50, 54, 55, 57, 64).

Carlsen et al. (18) loaded cars at shipping point in the Pacific Northwest using disposable pallets in an attempt to improve handling. While this technique may eventually become practical, it added too much cost in 1955.

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WAXES AND SKIN COATINGS

Many attempts have been made to retard transpiration and fruit metabolism by waxing or by various other skin coatings (1, 2, 6, 8, 11, 12). 1/ Christopher et al (3) showed the importance of very high humidity in reducing moisture losses of apples in cold storage. Often, even with high humidity, moisture loss from fruit is excessive during prolonged storage. Werner and Kitzke (13) pointed out that waxes, if properly used, can improve appearance, reduce moisture loss, respiration, and friction injuries, and serve as carriers for fungicides, etc. On apples, waxes and oil coatings are seldom used commercially.

Since 1945, Pieniazek and Christopher (10), Linde and Kennard (9), and Ford and Alban (4) have shown that wax emulsions can reduce weight loss of apples in storage. Pieniazek and Christopher (10) found that the reduction in rate of transpiration with wax emulsions of different concentrations was not constant through the storage period. A high concentration of wax emulsion increased the rate of transpiration immediately after application. Later it dropped much below that of untreated apples. Golden Delicious apples treated with wax emulsions had a better appearance after storage than nontreated fruit. Respiration was reduced about 10 percent by the wax treatment, according to Ford and Alban (4).

Hulme (8) and Trout, Hall, and Sykes (12) reported that oil emulsions affect storage behavior by modifying the concentration of carbon dioxide and oxygen within apples. On the Granny Smith variety, oil coating (castor oil and shellac) caused a marked retardation of normal skin yellowing, which is controlled by the internal oxygen supply (12).

Oil coatings reduced respiration of both pears and apples (11, 12). Reyneke and Pearse (11) found that the reduced rate of respiration was accompanied by a reduced rate of acetaldehyde production, which delayed the onset of storage scald. Hall, Sykes, and Trout (5) reported that a 7½-percent coating of castor oil and shellac reduced scald. They found that the storage life of apples in a nonrefrigerated storage was often increased as much as 50 percent with oil coatings. The prolonged storage life was attributed to increased carbon dioxide and decreased oxygen in the internal atmosphere (7). Oil coatings reduced scald more than the use of controlled-atmosphere storage did.

Hulme (8) listed three factors affecting the usefulness of oil coatings: the maturity and temperature of fruit when coated, the degree of emulsification of the skin coating, and the oil concentration in the coating emulsion.

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SHIPPING CONTAINERS AND CONSUMER PACKAGING [1/]

Many changes in the packaging of apples have occurred since 1945, both in shipping containers and in the use of consumer packages (4, 5, 17, 42, 52, 78). [2/]

Shipping Containers

The corrugated or fiberboard carton, used both in storage and in shipping, gradually displaced the wooden northwestern and eastern boxes, the bushel basket, and the returnable crate. In many fruit growing regions of the United States, the changeover to corregated cartons was nearly 100 percent by 1960. For export, some regions still make wide use of wooden containers (17, 58). The search for new or improved containers was brought about by increasing costs of box shook, the shortage of good timber, and the need for better product protection (1). Various containers in common use for apples were described by Carey (12). The corregated carton used with molded pulpboard layer trays has standard inside dimensions of 11½ x 12 x 20 inches. However, cell-type packaging requires partition cells and corrugated cartons of a different size and shape for each size apple. Duvekot (24) tested various arrangements of apples within tray, cell, and layer packs to study the possibility of container standardization. Diagonal packing was more flexible than rectangular arrangements and offered more possibility of packing different sizes in the same container.

There have been several studies of the advantages and disadvantages of wood versus corrugated containers (1, 43, 60, 85, 89). The Washington State Apple Commission (1) found that corrugated cartons delivered fruit to retailers with far less damage than the northwestern box. The carton almost eliminated severe bruising, partly because the carton pack had no bulge. The corrugated cartons cost less; assembly and lidding labor were less; labeling costs were less because cartons were preprinted; freight was saved since cartons weighed only half as much as a box; and no box liners were needed. The Commission estimated that use of corrugated cartons would save $80 per carload. Jacobsen (43) pointed out that cartons can be left folded until needed, so they take less storage space than boxes. Unseasoned wood boxes have occasionally damaged unwrapped apples; western red cedar and redwood were reportedly responsible (20).

An early disadvantage of cartons was that they appeared slack on arrival in markets, since they had no crown. Use of tier pads or trays reduced settling in cartons. Another disadvantage was that cartons had less stacking strength than boxes and were, therefore, less suitable for storage (1, 7, 8). However,

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1/ See also section on Bruise Control.
2/ Underscored numbers in parentheses refer to Literature Cited, p. 43.

many cartons now use containerboard which is water resistant or has wet-strength properties. Racks and supported stacks are one solution for storage of corrugated cartons. Duvekot (25) in Holland reported the results of 4 years' tests with 10 types of wooden storage boxes for apples and concluded that the best container was the standard fruit box with a complete corrugated liner.

Many improvements have been made in the strength of cartons. Beardsell (7) showed that there is still a need for a container that is truly rigid when wet. Improvements in the form of coatings, laminations, extrusions, impregnations, and additives of various sorts are available. Supports within cartons could be added to give greater stacking strength, but these increase cost.

Blanpied, Markwardt, and Ludington (8) tested various containers stacked 10 high at 32° F. and 85 to 90 percent relative humidity for 6 months. After storage, fruit was removed and the containers compression tested for stacking strength. Corrugated box liners measurably increased the strength of lidded corrugated apple containers. Telescope corrugated containers had greater stacking strength than comparable regular slotted containers.

Woodward (89) tested 11 containers of 3 types (wood, corrugated, and wirebound) for ability to protect apples from bruising. He found that apples in cell-packed cartons showed the least bruising, particularly in long-distance shipping. Apples in tray-packed cartons were second best, while jumble-packed apples in cartons showed the most bruising. Similar conclusions were reported for Sturmer apples in Tasmanian shipping tests by O'Loughlin (58), O'Loughlin and Shapman (59), and Chapman (17). Jacobsen (43) in Australia found significantly more bruising after shipment in wooden boxes (unlidded) than in jumble-filled cartons, and he recommended cartons for shipment of fruit to local markets. A preliminary finding in shipping tests to London using 6 container types was that Jonathan apples in cell-packed cartons arrived in better condition than in any of the other containers. In Sweden, Nyhlen (57) found that corrugated boxes caused less shipping damage than wood boxes and were easier to pack.

Fountain (29) tested 1/8-inch thick polyurethane layer pads as a possible substitute for molded trays in corrugated cartons. The polyurethane pads were not adequate in thickness or density to protect apples from bruising. Bruising was considerably more serious with the plastic pads than with the conventional molded pulp trays. He also evaluated polystyrene (3/8-inch thick) foam layer pads for apples. However, these pads cracked, ruptured, and allowed excessive bruising compared with molded pulp trays.

A lenticel injury on Golden Delicious due to formaldehyde given off by certain wet-strength agents used in the manufacture of molded-pulp trays was reported by Ginsburg (31). New formulations have eliminated the injury.

Cooling Rate in Various Containers

Considerable information is available on the cooling of apples in cartons compared to that in wood boxes (27, 31, 34, 36, 56, 60, 71, 72, 76, 83, 84). Wood boxes were usually packed with a bulge which, when the boxes were stacked, left more sides exposed for cooling. The new telescope-type corrugated cartons had no bulge. When they were stacked tightly together in storage, cooling was very slow.

Both Hall (36) and Sainsbury (72) have stressed that satisfactory cooling is not possible unless there is a good flow of air around containers to permit quick transfer of heat from fruit. Packages which do not have internal interferences to airflow are cooled effectively by convection. If multiple packages

are to be cooled by convection on a pallet, the vents in containers should be arranged to line up and provide a continuous passage from one exposed face of the load to the other (72). Hall (36) showed stacking patterns recommended for quick cooling of cartons on pallets and described open-chimney, parallel, and cross-stacking arrangements.

Sainsbury (71) found that apples in unvented cartons often took three times as long to cool as in wooden boxes and the fruit remained two degrees warmer at equilibrium. He tested different amounts of carton ventilation and recommended two vents (3/4" x 2") at each end. Vented cartons with perforated trays allowed tray-packed apples to cool in half the time required for unvented cartons and provided performance equal to that of the old standard wrapped pack in wood boxes. The vents and perforated trays allowed an equilibrium temperature only 0.8 degree above storage air temperature. Sainsbury (71) stated that stacking for good cooling should allow a surface exposure equal to two ends of a carton.

Fisher (27) also found that tray- and cell-packed cartons were significantly slower in cooling when unvented. Only with two side vents and two end vents was carton cooling as fast as in wood boxes. Top boxes in stacks cooled more rapidly than center boxes, as might be expected. Spacing between rows and stacks was most important. Fisher stated that cooling with rows 3½ inches apart and stacks 3/4 inch apart was better than with rows 1½ inches apart and stacks tightly together. With the smaller spacing between rows, it took 4 days longer for fruit to reach 35° F.

Guillou (34) showed that venting corrugated cartons speeded cooling by exposing some of the surface inside the box. He used a rule of thumb that each 1 percent of box surface removed, reduces fruit cooling time by about 5 percent. Guillou reported that wood boxes and corrugated cartons cool at about the same rate when stacks are equally exposed in storage.

Olsen, Patchen, and Schomer (60) showed that cartons tightly stacked together cool slowly and never reach a temperature as low as in bulge-packed wood boxes. They noted that vents in cartons did not take the place of proper spacing. Their results showed that perforated trays and the small vents being used commercially in cartons did not markedly increase the cooling rate of enclosed fruit. But proper spacing greatly facilitated cooling of cartons compared with close stacking. Hall (36) reported similar test results in 1962.

Truscott (83, 84) has developed much information on ventilation of wooden containers to facilitate cooling. He reported that both top and bottom of 40-pound containers should have a minimum of 20 square inches of ventilation openings to allow adequate cooling.

Noordzij (56) presented the theoretical approach to cooling fruit in containers by calculating cooling curves.

Shadburne (76) tested various truck loading patterns with McIntosh apples in corrugated cartons in shipments from New York to Florida. Load patterns which contained air channels the entire length of the load permitted better refrigeration and more uniform fruit temperatures in transit.

Consumer Packaging

Consumer packaging or prepackaging of fresh produce developed along with the growth of the supermarket. Prepackaging of apples and other produce was necessary if produce departments were to become self-service, as in other departments. Pioneering research on produce prepackaging was directed by Hauck

at Ohio State University in the mid-1940's (40, 41). It was estimated that between 30 and 45 percent of all fresh fruits and vegetables were sold in consumer packages in the United States in 1960 (2, 79). Good discussions of the growth of prepackaging and of produce packaging requirements have been published (2, 13, 19, 37, 38, 53, 73, 79, 80, 88). In the face of growing competition from processed fruits and vegetables, some experts felt that to reverse declining sales, 100 percent prepackaging of fresh produce was needed (2). Carlsen and Stokes (14) reported that 98 percent of 4,500 respondents to a survey indicated they would buy more apples if prepackaged.

In 1960, about 45 percent of all apples sold were prepackaged in film bags, according to U. S. Department of Agriculture estimates (2). The extent of apple prepackaging varied markedly in different sections of the country. It was very high in the Midwest and Northeast. Brunk (10) found that as early as 1953, 78 percent of the apples sold in New York were in polyethylene bags. Continued growth of consumer packaging seems assured.

Consumer packaging of apples is done in production areas, in central warehouses, in terminal markets, and in retail stores. Cravens and Bere (21) found that prepackaging costs were about 20 cents less per bushel, if packaging was at the country level rather than in retail stores. Carlsen and Stokes (14) also found that it was economically feasible to prepackage apples at shipping point. Carey (13) has discussed the pros and cons of packaging fruit at various levels.

Advantages of prepackaging, often cited by growers, were that it was a good way to market small apples, that it increased apple sales and gave a higher net return (66). Sherman, Sharp, and Mitchell (77) reported that the 2¼-inch size of apple was packaged more than any other size. They also found that spoilage losses for Ohio apples were very low in consumer packages.

Types and Sizes of Consumer Packages

The polyethylene bag is the standard consumer package for apples, especially for the smaller sizes. Various procedures are available for packing in film bags (55). Standard thickness of film is 1.25 or 1.5 mils (.00125 or .0015 inch). Sherman, Sharp, and Mitchell (77) reported that 1.5-mil film was strong enough even for 8 or 10 pounds of apples. The cost of plain polyethylene bags in 3-, 4-, or 5-pound sizes was approximately $7, $8, or $9, respectively, per thousand in 1964. The use of cotton- or paper-mesh bags for apples has practically disappeared because of their higher costs. Pliofilm and semimoistureproof cellophane film bags have been used to a minor extent (14). Description of various films available for produce packaging, including gas permeability data, were published by Rogers (70) and Soso (78).

Rasmussen and Thomas (66, 67) found that over four-fifths of the apples packaged in the Northeast were in 3-pound polyethylene bags.

Various other types of consumer packages have been tested because of some reports of excessive bruising in jumble-packed film bags (11, 14, 26, 28, 39, 42, 46, 54, 63, 64, 75, 87). Perkins and Underwood (63) tested molded-pulp trays holding 6 or 8 apples and polyethylene bags with a cell partition insert to separate apples. They reported 50-percent less damage to McIntosh apples in these containers during shipment compared with that occurring in jumble-packed polyethylene bags. Cairns, Carlsen, and Chapogas (11) and Havas, Henderson, Parsons, and Schaffer (42) also studied open-top trays, tape-wrapped trays, sleeve-wrapped trays, and complete film-wrapped trays for medium- and large-size

apples, and presented weight loss, decay, and shriveling data. Kattan (44) developed a machine that packs fruit in perforated polyethylene consumer pouches, with 3 to 4 fruits per pouch and no tray. The pouches are connected in a continuous ribbon, but can be separated.

Use of shrinkable films to immobilize fruit was an innovation of the early 1960's. Shrinkable polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyester, plasticized vinyl, and Pliofilm became available (3, 28, 30, 47, 70). Fountain (28) evaluated shrinkable films for overwrapping medium-size Delicious and Winesap apples at shipping point in Washington. A consumer unit of 6 or 8 apples in a molded pulp tray was overwrapped with shrinkable film. Then packages were conveyed through a 300° F. heat tunnel. The film was drawn tightly around the package without damage to the fruit from the brief heat treatment.

Shipping tests of this type of consumer package were made from Washington to eastern markets in cell-type master containers. Fruit arrived with very little bruising, only 2.7 percent slight bruising on Red Delicious and 3.5 percent slight bruising on Winesap. Cost of material and labor for the shrink-film package was 2.2 to 2.4 cents a pound compared with 1.7 cents a pound for conventional tray-packed cartons.

Fountain (28) developed a cell-type shipping container, in which each consumer package was held securely in an individual compartment by separators that prevented upper layers from pressing on lower layers, and substantially reducing bruising.

Moyer (54) and Lins (46) described a shrink wrapping operation in the eastern United States in which a sleeve wrap (open ends) of 75-ST Vitafilm was used over molded pulp trays. Smaller apples were placed in trays holding 3 or 4 pounds. Larger apples were packed by count in trays holding 4, 6, 8, or 10 fruit.

Churchill (18) reported good expansion of shrink packaging for Golden Delicious (6 per tray) in Washington State in 1963, although total volume was still small. Shrink-wrapped trays of Golden Delicious packed in production areas in shipping containers arrived at markets in as good or better condition as Golden Delicious in cell-packed corrugated cartons. In another study with McIntosh apples (16), four types of packages were evaluated for protection of fruit during shipment. Cell cartons gave the most protection from rough handling, but apples prepackaged in trays with heat shrinkable film overwraps and packed in cartons were next best protected.

Physiology of Packaging and Film Requirements

Several investigators have studied the microclimate within various types of film packages containing apples or other fresh produce (19, 26, 37, 38, 39, 48, 49, 65, 68, 74, 75, 81, 82, 86, 88). After packaging, apples continue to respire, use the available oxygen, and give off carbon dioxide, water, and heat. If the consumer package does not allow for entrance of oxygen, the supply is soon exhausted and respiration becomes anaerobic. In anaerobic respiration (respiration in absence of free oxygen), alcohol and carbon dioxide are produced, which can produce an off flavor and eventually kill the tissue. Apples may also be injured merely by the accumulation of carbon dioxide. Hall (35) found that Granny Smith apples stored at 68° F. in 1.5-mil polyethylene bags accumulated 6 percent carbon dioxide in 6 hours and up to 12 percent carbon dioxide in 12 hours.

Films must be used for consumer packaging that will allow entrance of sufficient oxygen and escape of carbon dioxide to prevent damage to fruit. In 1946, Platenius (65) showed that a single 1/4-inch vent hole in a film-wrapped consumer package would prevent anaerobic respiration. Many types of films do not have adequate permeability to the respiratory gases to prevent possible harm, so use of perforated or ventilated films has become standard practice. Scott and Tewfik (75), Claypool (19), Schomer (74), Hardenburg (37, 38), Hall (35), Duvekot and van Hiele (26), Avall (6), Marcellin (48, 49) and Tomkins (81, 82) have elaborated on the need for adequate film permeability or artificial film ventilation.

Tomkins (82) has shown that the concentration of carbon dioxide rises until the pressure is such that the rate of escape by diffusion through the film or through perforations is equal to the rate of production. The concentration of oxygen meanwhile falls until either the rate of passage of oxygen into the bag is equal to the rate at which it is used up or anaerobic conditions are established.

Scott and Tewfik (75) tested 15 kinds of film for packaging Gallia Beauty apples. After 5 days at 72° F., the oxygen within the packages ranged from 0.3 to 5.6 percent and carbon dioxide from 14 to 30 percent. These high carbon dioxide and low oxygen levels had deleterious effects on the apples. The extent of alteration of the atmosphere in the packages depended upon the temperature and the time, as well as the type of film. The respiration rate of apples packed in several of the films was lower than for unpackaged apples. Hardenburg, Schomer, and Lieberman (39) showed that adding a small amount of ventilation to packaged apples had a negligible effect on weight loss. Apples bagged in LSAT cellophane and stored 7 days at 70° lost 0.6 percent moisture in non-vented bags, 0.8 percent in bags with two 1/4-inch holes, and 0.9 percent in bags with many U-shaped die-cut flaps. Two 1/4-inch holes in these cellophane bags kept the oxygen at 19 to 20 percent and the carbon dioxide under 1 percent at 70°. No off-flavor developed during 2 weeks at 70° in sealed LSAT cellophane bags. However, Jonathan, Winesap, and Golden Delicious packaged in sealed polyethylene or 120 FF Pliofilm bags developed fermentation flavors within 2 weeks at 70°. These films should be ventilated if used for apples. Ritter and Thomas (68) found that the flavor of Rome Beauty apples stored 2 weeks at 35° in nonperforated polyethylene bags was inferior to that of fruit in perforated bags.

Several reports show that a high relative humidity builds up within moisture-retentive packages from the water vapor given off by produce (19, 26, 37, 74, 82). This high humidity, approaching 100 percent, favors the growth of decay-producing microorganisms. As a result, decay may be worse in consumer-packaged produce than in bulk. Hardenburg (37) showed that by increasing the number of ventilation holes in a film package, beyond those needed to let oxygen enter and carbon dioxide escape, the relative humidity could be maintained at more desirable levels of 90 to 95 percent. He suggested 16 ¼-inch holes for 5-pound polyethylene bags of apples. In commercial practice, 16, 24, or 32 perforations are commonly used for 3-, 4-, or 5-pound bags. Even with 16 to 32 perforations, moisture loss from apples in consumer packages is markedly less than from nonpackaged apples.

Schomer (74) studied numerous films for produce and concluded that choice of film depends on several factors, besides its value in preventing moisture loss and shriveling. Other factors were ease of handling, durability, appearance, transparency, cost, and adaptability to machine wrapping.

Effect of Consumer Packaging on Quality

The main values that may accrue from prepackaging apples, in regard to quality maintenance, are protection from moisture loss and prevention of mechanical damage (38, 74). Godwin (32, 33) in an early study on marketing film-packaged apples found that spoilage was the main source of loss in packages. Sherman, Sharp, and Mitchell (77) reported that spoilage losses during marketing were very low for packaged apples in 3-, 4-, 5-, 8-, and 10-pound bags. There was usually less waste in prepackaged apples than in bulk. Ritter and Thomas (68) found that Stayman and Rome Beauty apples could be prepackaged in polyethylene bags at harvest, and still be as acceptable as conventionally stored fruit after 10 weeks at 35° F. Their data indicated that flavor and texture of these two varieties in perforated bags and in bulk were essentially similar after 2, 6, 8, and 10 weeks' storage.

Prevention of mechanical injuries is one value of a good consumer package for apples (15, 16, 28, 42, 50, 51, 52, 61, 62, 63, 69). Perkins (61, 62) and Ceponis and Kaufman (16) noted that polyethylene bags did not give good protection from bruising to soft-fleshed McIntosh apples. Perkins (61) and Nyhlen (57) found that less damage occurred during shipment in master containers if the film bags were packed horizontally rather than vertically. Damage in bags in the vertical position increased with the depth of the apples. Ceponis, Kaufman, and Ringel (15) surveyed the quality of prepackaged McIntosh apples in New York City retail stores. Punctures by stems and bruising were the most serious defects, and they increased at each step during marketing. The consequence of the bruising and punctures was decay, often within 1 week at 70° F. after apples were prepackaged.

While bruising has often been serious in jumble-packed polyethylene bags, it usually has been less than for apples marketed in bulk displays. Merchant and coworkers (51, 52) reported less bruising of McIntosh apples prepackaged in polyethylene bags and in carryout chipboard cartons than when displayed in bulk. Bruising in consumer bags was reduced by using chipboard dividers or cell-partition inserts to separate the apples. The use of shrinkable films to immobilize apples within a tray reduced damage in marketing still further, as mentioned earlier (28). Merchant et al. (52) showed that apples in consumer bags in the bottom layer of master containers showed more bruising than those in the other two layers.

Consumer packaging is not a substitute for refrigeration. Hauck (40) and Avall (6) showed that prepackaging plus refrigeration produced results much better than either alone. Prepackaged Rome Beauty apples had a shelf life of 20 days on a nonrefrigerated counter averaging 73° F. On a refrigerated counter averaging 47°, the shelf life was 31 days (40). Schomer (73, 74) also stressed the value of refrigeration for quality maintenance of packaged produce. He noted that refrigeration was usually more important than choice of film for prepackaging in preventing deterioration. Quality retention in consumer-packaged apples was progressively better with lowering of storage temperatures to 31° to 32°.

Roberts (69) noted that refrigeration of prepackaged apples was desirable during marketing, particularly during retail display, if apples were to reach customers in good condition. Havas, Henderson, Parsons, and Schaffer (42) reported that the type of consumer package did not affect the keeping quality markedly, if apples were displayed under refrigeration. Weight losses and decay were greater when apples were displayed without refrigeration than they were

with refrigeration. Weight losses after 7 days on a nonrefrigerated counter were 3.4 percent for bulk, 2.6 percent for sleeve-wrapped trays, and 1.1 percent in perforated polyethylene bags. After 7 days in a refrigerated display, weight losses were 2.4 percent for bulk apples, 1.0 percent in sleeve-wrapped trays, and 0.6 percent in polyethylene bags (42). Other merchandising procedures are evaluated by Dalrymple (22), Brunk (9), and Dominick (23).

Master Containers

Most prepackaged apples are shipped with 9 to 15 bags in corrugated cartons, often with dividers between the bags. The arrangement of bags or other consumer packages within cartons is not standardized. The corrugated cartons are made of 175- to 275-pound test board (67).

Cairns, Carlsen, and Chapogas (11) found that corrugated pads were needed between layers of packages in master containers to minimize bruising. Perkins (61, 62) conducted shipping tests of McIntosh and Starr apples in polyethylene bags, and found less bruising on arrival at terminal warehouses when bags were packed horizontally rather than vertically. In the vertically packed cartons, 12 bags were in a single tier, with 2 bags in each of 6 cells. In the horizontally packed cartons, 12 bags were in 2 tiers, with 6 on the bottom and 6 on the top. Severe bruising after shipment amounted to 38 percent in the vertical pack, and only 12 percent in the horizontal pack. There was no difference in cost of the two types of master containers.

Merchant, Gavett, Underwood, and McDonald (52) noted that use of 275-pound test strength master containers resulted in less bruising than 200-pound test containers. Levin and Gaston (45) pointed out that master containers should not be so small that packers have difficulty in putting the required number of bags into them. Nor should they be so large that bags will shift during transit and bruise the fruit.

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FILM BOX LINERS AND PALLET COVERS

There has been much interest since 1945 in possible use of various moisture-retentive films to aid quality preservation of fruit during storage. Early research was aimed primarily at evaluating films for reducing transpiration losses from apples. McMahon (49) found that wax emulsions were much less effective than several kinds of film in preventing moisture loss from Golden Delicious apples. 1/ Box liners with lapped, sealed corners were more effective than those with open corners.

About 1950 Gerhardt (16) began testing polyethylene film for pears and Golden Delicious apples at Wenatchee, Wash. Polyethylene was relatively inexpensive and had several desirable physical and chemical characteristics not possessed by other moisture-retentive films. Gerhardt found that the appearance and dessert quality of Golden Delicious apples in sealed film liners of 1.5-mil (.0015 inch) polyethylene and Pliofilms 80 FMI and 80 HP after prolonged storage were still excellent. Shriveling was eliminated. He recommended that film liners be perforated or slit open on removal from storage to prevent possible injury to the fruit from inadequate gas exchange at higher temperatures.

Limited commercial use of polyethylene liners started in 1952 (17). Since then use of polyethylene liners to prevent shriveling of Golden Delicious has expanded to other sections of the United States and to some other countries. Nicolaisen-Scupin (54), Hardenburg, Schomer, and Uota (30), Heinze and Hardenburg (32), and Goidanich and Pratella (18) have published reviews on the use of polyethylene for produce packaging.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 58.

Hardenburg (23) and Workman (79) showed that it was not necessary to use sealed liners to prevent shriveling of Eastern-grown Golden Delicious. The top of the film liner could be merely folded over the apples to maintain a high humidity, or perforated liners could be used. After 6 months' storage at 31° F. in boxes with polyethylene liners, Golden Delicious were still in good condition with negligible shriveling and only about 1-percent weight loss. Results of storage tests with Golden Delicious in polyethylene box liners over a 7-year period were reported by Hardenburg and Anderson (28). Tindale (73) states that in Australia many growers prefer to use a single sheet of polyethylene to line sides and bottom of boxes, but not at the ends. The sheet is then merely folded over the fruit at the top and the humidity stays high and reduces shriveling of Jonathan and other varieties.

Effect on Moisture Loss and Shriveling

Film box liners can be extremely effective in minimizing loss of moisture, thereby preventing shriveling in storage. They have been widely evaluated for this effect (1, 3, 4, 8, 10, 16, 17, 18, 19, 20, 23, 24, 28, 29, 31, 34, 43, 47, 48, 49, 51, 54, 57, 58, 62, 63, 66, 67, 68, 70, 71, 72, 73 ,77, 79). Schomer (68) reported that Golden Delicious packed in cell-packed corrugated cartons with polyethylene liners kept much better than without liners, because loss of moisture to the cartons was reduced. Without film liners moisture loss averaged 5 to 6 percent after prolonged storage at 31° F. With film liners, moisture loss was not over 2 percent. Under more severe conditions, Dana (8) reported 11.8 percent moiture loss after storing Golden Delicious 4 months without polyethylene liners, 4.1 percent in film with 100 perforations, and 0.7 percent in nonperforated sealed liners.

Polyethylene may also be used as bulk-box liners, bulk-box covers, or pallet covers over 24 to 36 field boxes to prevent moisture loss from apples (9, 29, 55). Individual 1.5-mil polyethylene liners in field boxes or in corrugated cartons were more effective than 2-mil pallet covers in preventing shriveling of Golden Delicious (29). However, film pallet covers over field boxes prevented serious shriveling and offered the advantage of lower cost than individual box liners plus ease of application after precooling.

Polyethylene can largely prevent shriveling of any apple variety, but Golden Delicious is a variety with a skin texture that loses moisture most readily. Other varieties that shrivel and sometimes benefit from storage in polyethylene are Secor, Golden Russet (8), Red Steele (9), Jonathan (31, 48, 50, 58), Laxton's Superb (10), Stayman Winesap (18), Turley (81), and Yates (51).

Effect on Decay, Breakdown, Scald, and Other Disorders

There have been many conflicting reports on the effect of film liners on decay, breakdown, and scald on various varieties. Padfield (58) in New Zealand has not recommended liners even for Golden Delicious because of physiological disorders and the possibility of off-odors. The high relative humidity maintained within liners does make conditions ideal for growth of decay microorganisms, especially if apples are not from clean orchards, are not precooled, or are not stored at optimum temperatures. Workman (79, 80), Ryall and Uota (64, 65), Hardenburg and Anderson (27, 28), Gerhardt (16), Gerhardt and Schomer (17), Duvekot (10), and Ulrich and Leblond (77) found that sealed polyethylene liners

did not increase decay of various varieties of apples during storage. The accumulation of carbon dioxide within liners was probably of some value in retarding spoilage. Säkö (66) reported that polyethylene reduced storage losses during the first 8 to 10 weeks, but thereafter it increased the liability to spoilage. Smock and Blanpied (70) found that polyethylene liners increased decay of McIntosh, Cortland, Delicious, Golden Delicious, Stayman, and Jonathan.

Jonathan spot has been controlled or reduced by use of sealed polyethylene liners (31, 68, 70, 79). Sealed liners are used commercially by a few packers to control both Jonathan spot and soft scald (30, 68). An atmosphere of 3.5 percent oxygen and 7 percent carbon dioxide within liners controlled these two physiological disorders. Nel (53) found that apple spot on the Ohenimuri variety was reduced by polyethylene liners.

Internal breakdown has been accentuated with film liners used on several varieties. Padfield (58) observed increased internal breakdown of Jonathan apples in sealed liners. Hardenburg and Siegelman (31) observed this in Jonathan and Arkansas apples in nonsealed liners. Smock and Blanpied (70) noted increased internal browning of Jonathan in one test with sealed liners. Ulrich and Leblond (77) found increased internal browning in Belle de Boskoop apples stored 7 months at 4° C. in polyethylene lined boxes. Mattus (47) found severe breakdown in several lots of Golden Delicious in Virginia after only 2 months' storage in polyethylene liners. Some of this deterioration may be attributable to accumulation of carbon dioxide within the liners.

Polyethylene liners have given extremely variable results on incidence of scald. Factors such as film thickness, film density, variations in film permeability, tightness of seams and closures, film perforations, and apple varietal differences are responsible (27). If film liners are left unsealed or are intentionally or unintentionally perforated or torn, scald is often increased over that in unlined boxes (27, 28, 31, 58, 70). Sealed polyethylene liners usually reduced or controlled scald (27, 31, 64, 65, 70, 77, 79). Sometimes, however, sealed liners did not reduce scald and even increased it on certain varieties (8, 19, 27, 50, 58, 62, 70, 71, 73). Padfield (58) and Rasmussen (62) found that sealed liners increased scald of Jonathan apples. Stevenson and Blake (71) noted that sealed liners increased scald on Granny Smith. Dana (8) and Smock and Blanpied (70) found that sealed liners increased scald of Cortland and McIntosh apples. Smock and Blanpied (70), Rasmussen (62), and Gorini (19) found some increase in scald on Golden Delicious in sealed liners. Both Gorini (19) and Hardenburg and Anderson (28) noted that on Golden Delicious the yellowest or most mature apples scald the most in polyethylene liners. Oiled wraps or chemical inhibitors were helpful in controlling scald within liners (27, 81).

One of the keys to scald control on fruit in film-lined boxes was found to be the oxygen level maintained around the fruit by the liner. If oxygen is maintained at a low level, scald is reduced (27, 70, 79). Workman (79) reported that scald on Rome Beauty apples was markedly reduced if the oxygen was 2 to 10 percent within the liners. Hardenburg and Anderson (27) noted that in perforated liners with 18 to 20 percent oxygen scald was not reduced. If sealed liners had an intermediate oxygen level of 8 to 12 percent, scald was reduced somewhat, but the extent depended on the variety. In sealed liners with oxygen at a low level of 3 to 5 percent, scald was largely controlled.

The oxygen level must be low during the first month of storage to control scald in sealed liners (27, 70). Any delay in packing apples reduced the effectiveness of sealed liners in controlling scald. This was illustrated in a test by Hardenburg and Anderson (27) with Rome apples in which fruit in unlined boxes

was 100 percent scalded after 6 months' storage at 31° F. plus 6 days at 70°. Rome apples packed in sealed polyethylene-lined boxes immediately after harvest and after a delay of 1, 3, 5, 7, or 9 weeks at 31° had 21, 32, 52, 71, 77, and 95 percent scald respectively, after storage.

(See also section on scald.)

Effect of Firmness and Keeping Quality

The modified atmospheres which develop within sealed polyethylene liners retard the rate of softening of apples in storage (8, 18, 28, 31, 37, 56, 64, 78) and retard the rate of yellow color development (16, 28, 31, 52, 59, 64, 76, 78). Gerhardt and Schomer (17) found that Golden Delicious apples stored 6 months at 32° F. in sealed polyethylene or Pliofilm liners were better in appearance, condition, and dessert quality than check fruit. Sealed polyethylene liners delayed ripening of Golden Delicious, as apples in them had less yellow color after storage (28). Ryall and Uota (64) stored Yellow Newtown apples 6 months at 40° in sealed liners and found the fruit firmer, greener, and with less scald on removal. Okamoto, Horitsu, and Harata (56, 57) noted that Ralls apples after 6 months in sealed liners were firmer and more acid and superior in appearance to check fruit. Langerak (37) noted that Golden Delicious apples stored in polyethylene at low temperature were firmer and juicier, but flavor and aroma were often poor. Johansson (35) had good results with Cox's Orange and Ingrid Marie varieties in polyethylene. Several investigators (16, 17, 33, 34, 41, 61) have also found sealed polyethylene liners or bags beneficial in retarding ripening of pears.

Some apple veriaties have not kept better and firmer in sealed box liners. Workman (78) stated that Delicious apples became mealy. However, Hardenburg (26) found that if a 1-pound packet of hydrated lime was enclosed in sealed liners to absorb the carbon dioxide given off by Delicious apples, they stayed firmer than without the lime.

Hardenburg and Siegelman (31) showed that the benefit of slower ripening usually was not obtained with nonsealed liners for Jonathan, Grimes, Arkansas, and Rome Beauty varieties.

Both Gorini (19) and Okamoto, Haritsu, and Harata (57) have published very detailed studies of the keeping quality of apples in sealed polyethylene and included data on sugars, total acidity, moisture, firmness, and taste. Both studies included tests with two or more thicknesses of polyethylene.

Respiration has been measured on apples taken from film-lined boxes (16, 28, 56, 78). Gerhardt (16) showed that Golden Delicious apples previously held in various sealed films respired at a lower rate during cold storage than comparable fruit without film protection. Hardenburg and Anderson (28) showed that the poststorage respiration rate of Golden Delicious from sealed polyethylene liners was less than that of fruit from perforated liners or from control boxes without film. Workman (78) reported that sealed liners reduced respiration of Rome Beauty apples. Okamoto, Horitsu, and Harata (56, 57) reported that the superior keeping quality of apples in sealed polyethylene was due to a retarded respiration rate in the modified atmosphere.

Film Selection and Use

Various cellophanes, Pliofilms, and polyethylenes have been evaluated for possible box liner application (16, 39, 49). Falch and Pernerstorfer (15)

tested three types of Pliofilm liners for storing apples at 4° C. (39.2° F.). They obtained good results with Golden Delicious, Red Delicious, Berlepsch, and Canada varieties, fair results with Cox's Orange, and poor with Ontario. However, most research has been with polyethylene, usually 1.5-mil thickness. This film has the desirable characteristics of being easy to handle and differentially permeable to the respiratory gases. Depending on thickness, density, and method of manufacture, it is usually 3 to 5 times more permeable to carbon dioxide than to oxygen. It is also sufficiently moisture retentive for box liner use.

The original work by Gerhardt (16) on Golden Delicious apples showed that sealed 1.5-mil polyethylene liners maintained 3 to 4 percent carbon dioxide and 10 to 13 percent oxygen, which was beneficial. To avoid possible injury to the fruit, perforating or slitting the sealed film was recommended upon withdrawal from cold storage for marketing (16, 24, 27, 31, 78, 79). Commercially, film liners are often removed from boxes before marketing and sometimes are used again another season. However, reuse of liner is not recommended where sealing is desired, because any holes will prevent buildup of desired atmospheres (33).

Since the early work by Gerhardt, other investigators have found that 1.5-mil polyethylene film is not necessarily a safe film for sealed box liners (7, 10, 22, 27, 31, 58, 70, 73, 77, 78, 79). Injury in many different forms has been observed. Polyethylene from different sources varies in permeability. If made from low density resisn, it is much more permeable than if made from medium or high density resins (27). A polyethylene film with a low density of 0.914 to 0.920 was more desirable than one with a density of 0.928 or above. When the higher density film was used, the oxygen level sometimes dropped to 1 percent and the fruit showed low-oxygen injury.

Polyethylene is less permeable at low temperatures than at high temperatures. It is also less permeable at 2-mil than at 1.5-mil thickness. Hardenburg and Anderson (27) found that Grimes Golden and Rome packed in sealed 2-mil film liners maintained box atmosphere of 1 to 2 percent or less oxygen and 8 to 12 percent carbon dioxide at 32° F. This fruit was severely injured on examination. It had a fermented flavor, and in some boxes showed 50 to 70 percent visible injury from the low oxygen and high carbon dioxide concentrations. Okamoto, Horitsu, and Harata (57) tested three thicknesses of sealed polyethylene liners for Ralls apples. At 32° F. they had excellent results with 0.03 mm (1.2 mil) and 0.045 mm polyethylene, but with 0.06 mm (2.4 mil) film the storage life was shortened because of inadequate gas exchange.

Even with a given lot of 1.5-mil polyethylene liners, oxygen atmospheres maintained were not uniform (27). Carbon dioxide concentrations were maintained within a narrow range of 4 to 7 percent on several varieties, but oxygen levels were much more variable, ranging from 1 to 14 percent. Fruit variability was one factor responsible. Cowell and Scott (7) explained that the variable oxygen levels in sealed liners is an inherent feature of this storage technique. Sealed liners should thus be used only with varieties that have a reasonable tolerance to carbon dioxide and a wide tolerance to oxygen levels.

Perforated films have been evaluated in attempts to avoid possible injury from sealed liners (10, 12, 22, 27, 28). Duvekot (10) reported that Jonathan and Laxton's Superb apples needed one perforation in the top of sealed liners to avoid injury. Hansen (22) found that Golden Delicious kept very well in sealed polyethylene liners at 35° to 37° F., provided the liners were pierced to allow escape of carbon dioxide. Hardenburg and Anderson (28) showed that folded-top nonsealed liners maintain considerable modified atmosphere around

Golden Delicious in tray-packed telescope-type corrugated cartons stored at 32° F. Carbon dioxide within these folded-top liners ranged from 4 to 6 percent.

Such nonsealed or folded-top liners may not allow adequate gas exchange for fruit in cartons some years. For example, one season Mattus (47) found severe injury in tray-packed Golden Delicious packed with folded-top polyethylene liners when carbon dioxide reached 8 to 10 percent. An inverted tray was placed above the overlapped liner. Then, when telescope covers were added the liners were essentially sealed and the fruit suffocated. For safety, most liners for Golden Delicious are no longer sealed in the United States.

In Australia, nonsealed liners are recommended to prevent shriveling of Yates apples because carbon dioxide has caused injury some years in sealed liners (51). This injury to Yates apples in sealed liners occurred in light-crop years.

Stoll and Nyfeler (72) have stated that polyethylene readily takes up aromatic volatiles and that this can cause trouble in storage.

Eaves (12) suggested that chemical inserts can aid in controlling the atmosphere in sealed liners. He used impermeable Mylar polyester film as a box liner and enclosed small polyethylene packets of hydrated lime to absorb carbon dioxide and packets of calcium chloride to absorb moisture. The desired level of carbon dioxide was maintained by adding 1/4-inch holes or pinholes in the lime inserts. Oxygen was supplied by perforations in the Mylar liner. Use of lime inserts would appear to offer good possibilities for avoiding carbon dioxide injury.

Later, both Hardenburg (26) and Hansen (21) showed that a pound of hydrated lime enclosed in kraft paper or waxed paper pads could be used in 1.5-mil polyethylene lined boxes of apples or pears to absorb carbon dioxide. This was a way of avoiding brown core and other types of carbon dioxide injury. A 1-pound kraft paper pad of lime kept carbon dioxide below 1 percent in a bushel of apples packed in sealed polyethylene for 5 to 6 months at 32° F. (26). Without lime inserts, carbon dioxide ranged from 5 to 8 percent in sealed liners in six tests. Hansen (21), using waxed kraft paper to contain the lime, maintained carbon dioxide at a desirable 1.6 to 2.8 percent in sealed poly-lined boxes of pears.

Marcellin (42, 44, 45) and Leblond (38, 39) in France have done considerable research on films other than polyethylene for apples and pears. Where six or more boxes are enclosed in film, ethylcellulose had a desirable permeability for Golden Delicious. They showed that fruit could be stored at relatively high temperatures of 12° C. (54° F.), if enclosed in ethylcellulose. Tomkins (75) showed how carbon dioxide and oxygen change in sealed packages of various films and discussed the attainment of equilibrium. He calculated the effect of package size and weight of apples on the equilibrium concentration of oxygen and carbon dioxide within packages of various films. Pratella and Battistini (60) studied the ratio of weight and surface of polyethylene film necessary to develop beneficial modified atmospheres.

Tolle (74) developed a formula based on product need which should be useful in calculating approximate film permeability requirements for specific storage conditions. This formula considers five factors concerning the container and its contents and expresses the permeability requirements in terms of milliliters of carbon dioxide or oxygen per square meter of film per 24 hours at standard pressure and selected storage temperature. The equations, which are being tested in actual storage trials, appear to be a step toward obtaining film to meet specific packaging needs.

Jurin and Karel (36) used the results of respiration studies to predict optimum packaging conditions in polyethylene. They found that the theoretical steady-state concentrations of carbon dioxide and oxygen in polyethylene bags were in good agreement with experimental results with McIntosh apples in tests at 20° C. (68° F.). Marcellin (45) found that physiological packaging in plastic films which maintain a beneficial microclimate for apples is possible. However, many factors are involved other than just the choice of film.

Effect of Film on Cooling

Film liners retard cooling, but the amount depends on the type of container in which liners are used (30, 33, 35, 69). Schomer, Gerhardt, and Sainsbury (69) measured the time required for removal of three-fourths of the field heat from Golden Delicious in different containers. Fifty-six hours were required to remove three-fourths of the field heat of tissue-wrapped fruit in a wood box. In a cell carton it took 77 hours, and in a cell carton with a polyethylene liner, 99 hours. However, they concluded that this interference in cooling by polyethylene was not serious. Workman (79) stated that some precooling before packaging in film was desirable.

A package having poor cooling characteristics, such as a corrugated carton, when stacked in a manner that allows little surface presentations to the airstream, will not cool much more slowly when lined than when unlined (30). On the other hand, liners will alter the cooling of packages that are normally open so convection currents can pass through the fruit. Golden Delicious apples in a pallet load of field boxes required 29 hours for three-fourths cooling with no polyethylene cover. With a film pallet cover over the boxes, 66 hours were required for three-fourths cooling (30).

Dewey, Raphael, and Goff (9) found that it took 8 days for apples in the center of 18-bushel bulk boxes to cool to 36° F. in a 32° room. When these bulk boxes had a 4-mil polyethylene liner, it took 16 days for center fruit to reach 36° and the temperature stayed 1.5 to 3 degrees higher than in unlined bulk boxes.

Storage Temperature

Workman (79) stored several varieties at temperatures as high as 42° F. in sealed polyethylene liners without injury. However, he recommended keeping the storage temperature below 37° to avoid possible low oxygen or high carbon dioxide injury. Ryall and Uota (65) stored Yellow Newtown at 32°, 40°, and 45° in a 1.5-mil polyethylene. They found that carbon dioxide was maintained at 4 to 5 percent and oxygen at 3.0 to 7.5 percent at each storage temperature. Although respiration was higher at the higher temperature, the film also was more permeable at higher storage temperatures. Best results with this variety were obtained at 40°. Marcellin (44) reported that the composition of the atmosphere inside film liners depends but little on the storage temperatures. Marcellin (40, 44, 46) and Bouhier (2) had good success in storing the Calville Blanc and Golden Delicious apples at temperatures of 45° and 59° in sealed polyethylene, with a saving in refrigeration. Leblond (39) packed Belle de Boskoop apples in small 1 kilogram (2.2 pounds) polyethylene bags and stored them successfully for 5 months at 7° C. (44.6° F.). At this temperature an atmosphere of 6 percent carbon dioxide and 2 to 4 percent oxygen was maintained. Johansson (35) enclosed 5 tons of apples in a 1-mil polyethylene tent at 40°, and maintained a

beneficial atmosphere of 5 percent carbon dioxide and 15 percent oxygen. Murata, Tsai, and Ogata (52) reported that sealing Jonathan apples in polyethylene at room temperature preserved fruit quality as well as cold storage without sealing. Certainly length of storage would be critical when warmer than optimum storage temperatures are employed.

Film Liners to Provide Modified Atmospheres

Sealed film liners can provide modified atmospheres beneficial in extending storage life. However, as Smock and Blanpied (70) have shown, use of a controlled-stmosphere storage room was safer than use of sealed polyethylene liners. It appears that there are too many hazards for wide commercial use of sealed liners. Sealed polyethylene liners are used by some commercial growers, but the possibility of getting unsuitable film in which the oxygen level may drop too low and injure fruit always exists. There is insufficient control of the atmosphere within liners (28, 70, 73). With improvements in uniformity of films, some expansion of box liner use for apple storage is likely. Development of chemical inserts to control the atmosphere should be helpful (12, 21, 26).

Workman (78, 80) listed the main advantages of using sealed differentially permeable films to provide modified atmosphere: 1) No attention is required after packaging, 2) fruit can be removed from storage at any time, and 3) no large capital investment is required. Workman (81) compared CA storage and sealed polyethylene liners for Turley apples over three seasons. Sealed liners helped maintain quality but sometimes increased scald over that in CA. Stop-Scald treatment was beneficial in controlling scald in liners. McGlasson and Jacobsen (48) stored Jonathan apples 7 months in sealed 1.5-mil polyethylene liners and found the fruit kept almost as good as in a controlled-atmosphere storage. After 8-1/2 months, apples in controlled atmosphere were in a much better condition than those in film. Hansen (22) reported that Golden Delicious could be kept in good condition until March in polyethylene liners. Controlled atmosphere storage extended storage life of this variety to April and May. Unpublished tests by Hardenburg have shown that apples packed in sealed polyethylene liners should not be stored in a controlled atmosphere room. Both Red and Golden Delicious suffocated under such conditions.

Careful use of film liners can provide extended storage, intermediate between that in regular cold storage and that in a controlled-atmosphere storage. Leblond (38) stated that favorable gas concentrations can be obtained by wise selection of film.

Eaves (14) made successful shipments of apples from Nova Scotia to Trinidad using 1-mil Mylar liners in bulk bins (360 pounds). The liners were not sealed until after the fruit had been precooled. A 1.2 kg. (2.64 pound) perforated Mylar bag of lime was inserted under the fruit to absorb carbon dioxide.

In addition to box liners, pallet covers, and bin liners, some researchers have enclosed much larger volumes of apples in plastic film (11, 13, 35, 38). Eaves (13) in Nova Scotia has successfully tested economical 500- and 1,000-box storages with 1-mil Mylar polyester walls. A framework of 2" x 2" boards used with building paper supported the film, which was unrolled after precooling the fruit. Film was also spread on the floor and protected with building paper before loading with apples. After loading, all film joints were sealed with polyethylene tape. Accumulated carbon dioxide was removed by a hydrated lime scrubber. Eaves reported that McIntosh, Red Delicious, and Northern

Spy apples in separate plastic storage units were in excellent condition after 6 to 7 months. Care was necessary not to perforate the film walls by rough handling. Rodents were another possible source of leaks.

Chace, Dewey, and Pflug (5) enclosed 2,460 bushels of McIntosh apples in a tent made of 8-mil vinyl film within a regular storage room. Details of this technique are in the section on Controlled-Atmosphere Storage.

Johansson (35) found that a 1-mil polyethylene enclosure over approximately 250 boxes stored at 40° F. served as a satisfactory controlled-atmosphere chamber for Cox's Orange and Ingrid Marie apples. Leblond (38) reported that ethylcellulose was a good film for plastic gas storages at a relatively high temperature of 54°. He described the requirements of films for fruit storage as permeable enough to water vapor, very permeable to volatile organic materials and not very permeable to oxygen and carbon dioxide.

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STORAGE (GENERAL)

Apple storage research since 1945 has been concerned largely with studies of preharvest factors, temperature studies, volatiles, and controlled atmospheres as these affect the storage behavior of the fruit. Each of these areas of research as well as those areas concerned with storage disorders of the fruit are

the subjects of individual sections in this report. In addition to these specific topics a number of publications have appeared that provide a general coverage, in greater or lesser detail, of the various factors important to consider in the storage of apples (2, 3, 4, 5, 6, 11, 16, 17, 18, 19, 20, 22, 23, 25, 26, 27, 28, 29, 30, 31). 1/ Several papers discuss cold storage design, construction, equipment, operations, or costs (1, 7, 9, 10, 12, 21, 24), and one (8) is concerned with the possible use and management of an air-cooled or common storage for apples. A series of papers has also appeared that presents the results of a study of the within tree, between tree, and between season variation between apple fruits and its relation to keeping quality (13, 14, 15).

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PREHARVEST EFFECTS ON STORAGE QUALITY

A number of preharvest factors may affect the storage quality of apples. Research designed to examine some of these factors since 1945 has included studies of the nutritional status of the trees, climatic conditions (especially near harvesttime), and orchard sprays that have been used, particularly those sprays used to reduce preharvest drop.

Nutrition and Fertilizers

Reviews in the literature since 1945 pertaining to the effects of nutrition and fertilizer usage on storage quality are contained in a number of reports (10, 25, 32). 1/ Many of the citations in these references are to work prior to 1945.

Studies on the effects of fertilizers on apple quality or storage life have generally shown nitrogen to exert more influence than any other element.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 71.

Fisher and Porritt (21) in 1951 reported that the overapplication of nitrogen may impair the keeping quality of apples in British Columbia. Blasberg (7) found fruit from McIntosh trees given foliar sprays of urea to be softer than fruit from trees receiving a soil application of nitrogen. Smock and Neubert (48) and Weeks, et al. (69) also point out that too much nitrogen may result in soft fruit or fruit that is poor in keeping quality. Southwick (56) found indications that 2, 4, 5-trichlorophenoxypropionic acid would speed up the rate of softening of apples from high nitrogen trees sooner and to a greater degree than it would fruit from trees at lower levels of nitrogen. However, he pointed out that trees having the high nitrogen level also had lower potassium and magnesium levels and therefore one could not assume the effects to be entirely due to the higher nitrogen level. A nitrogen level in the foliage above 2.0 to 2.1% has been reported to reduce the quality of McIntosh and Northern Spy apples (17, 32, 47). Hill, et al. (32) found a negative correlation between the level of nitrogen in the foliage and the quality score of the fruit. Eggert, et al. (20), however, found a taste panel preferred McIntosh apples from trees having a high foliage nitrogen to those from trees with a low foliage nitrogen. The data of Eggert, et al., did agree with that of Hill and his co-workers, in that the softest fruit at harvest came from trees with the high nitrogen level, but after 3 months' storage this difference in firmness disappeared. Jonathan apples, too, were found to be softer when they came from trees whose foliage nitrogen was high than firmer fruit from low nitrogen trees (10). Ostrowska and his associates (44) found that Antonovka apples from trees fertilized with NP were firmer both at harvest and after storage than fruit from trees fertilized with CaNPK. A report of studies in New Zealand (63) stated that nitrogen reduced the storage quality of Sturmer, Cox's Orange Pippin, and Jonathan apples but had little effect upon Dunn or Delicious. Similar results were obtained on Cox's Pippin by Montgomery, et al. (42). Fruit from trees with a high N/K ratio has been found by some to indicate poor storage quality (32, 47). Contrary to these reports. Padfield (46) reported combined NPK fertilizers increased yields with no significant deterioration in keeping quality of the fruit, provided the quantity of N fertilizer was restricted to 2 pounds per tree.

Tiller and his co-workers (63) reported that the addition of P or PK to N fertilizers improved quality, though their best quality fruit generally came from unmanured trees. In general, P has been found to exert little if any marked influence on the storage behavior of apples (10, 32, 47). Bûneman et al. (10) one year found low levels of potassium were associated with an increase of internal breakdown in Jonathans. Hill, et al. (32) reported a positive trend between potassium levels of the foliage and the quality score of the fruit. Wallace (68) also reported instances of a flesh breakdown in fruit from trees deficient in potassium, but he also observed such breakdown to occur in fruit from high potassium areas. Barden and Thompson (1) found that even heavy potassium treatments had no effect on fruit color or storage life of Red Delicious apples.

The effects of boron on storage quality are also complex. Haller and Batjer (25) reported a number of varied effects resulting from the use of boron fertilizers. They found that borax applications did not consistently affect firmness, reduce scald in some varieties, or increase internal breakdown in Jonathans. Bramlage and Thompson (8) also found boron sprays increased the occurrence of internal breakdown of Jonathans. They further reported that multiple sprays of boron applied early in the season significantly reduced the

storage life of apples. Fisher and Porritt (21), reporting on apples in British Columbia, indicated that heavy applications of boron may impair their keeping quality.

Preharvest Sprays

Much of the research conducted prior to 1945 on the use of growth substances in orchard sprays to reduce preharvest drops of apples has been reviewed by Vyvyan (65). The greater part of this research was concerned with naphthalene acetic acid (NAA). Subsequent research revealed additional materials that would reduce preharvest dropping. Among the more effective of these were 2,4-dichlorophenoxyacetic acid (2,4-D) (2, 42) and 2, 4, 5-trichlorophenoxypropionic acid (2, 4, 5-TP) (19).

Although 2,4-D remains effective longer after application than NAA, its usefulness is limited because it is effective primarily on Stayman Winesap (27, 28) and Winesap (2, 4, 28). Both NAA and 2, 4, 5-TP effectively reduce drops on many varieties but 2, 4, 5-TP remains effective longer after application than NAA (19, 30). Aside from their drop-reducing abilities, both NAA and 2, 4, 5-TP have elicited variable responses on maturation, ripening, coloring, softening, and storage quality of the fruit.

Gerhardt and Allmendinger (22) did not find that NAA increased ripening or impaired storage quality of either Delicious or Winesap apples if the fruit was harvested within 2 weeks of the spray application. They later (23) emphasized the importance of picking the fruit within the recommended picking time for the variety, to avoid the possibility of increased ripening due to this spray. Marshall and his co-workers (38) did not find ripening to be increased by sprays of the methyl ester of NAA on Delicious, McIntosh, or Wealthy apples during 65 days' storage at 33° F. Others too, have reported no apparent effects on ripening or keeping quality as a result of preharvest sprays of NAA on apples (34, 64, 66, 67). Padfield (45) and McKenzie (39), on the other hand, reported a deterioration of storage quality on Granny Smith and an increase in storage losses of Jonathans when these fruit received preharvest sprays of NAA. Stevenson and Dodd (59) compared the effects of NAA and 2, 4, 5-TP on the storage life of Delicious and found NAA had an unfavorable effect on storage due mainly to the occurrence of greater amounts of superficial scald. Batjer and Moon (3) found that NAA stimulated ripening in such summer varieties as Close, Williams, and Duchess of Oldenburg but had no direct effect on ripening of such later varieties as Delicious. In 1949 Southwick (54) showed that methyl a-naphthalene acetate was capable of stimulating respiration, softening, and ground color changes in preclimacteric apples held at room temperature. Once the preclimacteric has passed though, he indicated, the fruit may not show such a response to this material.

A stimulation of the maturation and ripening processes or the possible reduction in storage life attributable to 2, 4, 5-TP has been recorded by a number of investigators (6, 13, 34, 36, 50, 55, 56, 60, 61, 62). However, some of these same investigators, as well as others, have not always found that 2, 4, 5-TP stimulated such processes or reduced the storage life of the fruit (5, 9, 13, 14, 15, 16, 26, 29, 31, 35, 41, 61, 62). Varietal differences may in part account for some of these conflicting observations. Thompson (61, 62) found that sprays of 2, 4, 5-TP stimulated ripening of summer varieties but had little or no effect on fall and winter varieties, results similar to those reported by Batjer and Moon (3) with NAA. Smock, Edgerton, and Hoffman (53) also reported

ripening of early and midseason varieties to be stimulated by sprays of 2, 4, 5-TP, NAA, or 2, 4, 5-TA.

Hoffman and Edgerton (33) reported no measurable difference in ripening in McIntosh apples sprayed with 2, 4, 5-TP or NAA when the two substances were applied on the same date. They also found no significant difference in firmness between treated and untreated fruit.

Efforts to reduce the ripening effects of stop drop materials by using maleic hydrazide sprays have met with partial success (49, 50, 52, 53). Crandall (12) found that preharvest sprays of maleic hydrazide had no significant effect on firmness of Delicious apples after 3 months' storage.

White and Rice (70) and White (71) reported that preharvest chemical sprays to promote red color development did not have a measurable effect on firmness of apples at harvest or after storage.

The effects of fungicide and insecticide sprays on quality and storage life of apples has been the subject of relatively little research (18, 24, 52). Neither 2,4-D no Parathion were found to impair the dessert quality or storage life of apples by Gerhardt and O'Neill (24). Smock and Palmiter (52) found Crag and sulfur sprays advanced maturity more than other fungicides, but they also found the type of fungicide had little effect on ripening in some years.

Red Sports

A comparison of the storage life of several standard apple varieties with that of their red bud sports was made by Clarke in 1949-50 (11). He found in four of five cases that the standard varieties kept better in storage than their red bud sports. Padfield (46) has also stated that the majority of bud sports and highly colored strains of well-known varieties reportedly do not keep as well as the standard varieties. Schomer (47a), however, found no differences in maturity or storage behavior between apples of three new red bud sports and standard Delicious or Starking.

Climate

Climate has been shown by several investigators to affect the keeping quality of apples. Smock (51) found in McIntosh a fair though not significant positive correlation between fruit firmness at harvest and solar radiation during the last 6 weeks of the growing season. He also observed scald susceptibility in McIntosh and Rhode Island Greenings was associated with high mean temperatures during the last 6 weeks of the growing season. The effect of temperatures in the field on scald susceptibility was studied in considerably greater detail by Merritt, et al. (40). These investigators found that when approximately 150 hours below 50° F. had accumulated (following the onset of consistently cool weather as the harvest period approached) most fruits were free of scald on removal from storage.

In a study of the storage quality of Golden Delicious injured by early season frosts Lott (37) found fruit so injured as to develop russet bands kept as well in storage as nonrusseted fruit.

Tree Age

Tree age as it might affect the storage life of apples was reported on by Stevenson in 1957 (57) and again in 1961 by Stevenson and Watkins (58). In the latter paper these authors reported that the age of the tree did not have any consistent effects on the incidence of storage disorders in the fruit.

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PRECOOLING AND TEMPERATURE EFFECTS DURING STORAGE

Temperature and precooling investigations in recent years have included studies on the effects of rapid cooling, gradual cooling, intermittent warming, and delayed storage as these factors affect the storage behavior of the fruit. Other investigations have considered factors that may affect the cooling rate of the fruit in storage, such as methods of cooling, nature of storage container (wooden box, fiberboard carton, pallet box, etc.), stacking pattern, and air circulation within the storage house. A number of publications contain summaries of apple storage temperature recommendations that have been established over the years (21, 28, 34, 39, 48, 65). 1/

Cooling Rate

Blanpied (2) was able to discern quality differences between McIntosh apples cooled at different rates through the first 3 months of storage. After 6 months' storage, however, differences in quality were not evident either by firmness measurements or by organoliptic testing. Poapst and Phillips (44, 45) found that rapidly cooled McIntosh retained somewhat better flavor during the first 4 months' storage than similar fruit cooled more slowly, but these flavor differences had disappeared by the end of 6 months. Smock (60) reported finding little difference in firmness after 4, 5, and 6 months' storage between apples that had been hydrocooled, cooled in 3 days, or in 1 week prior to storage.

Delay in Storage

Delayed storage is considered to reduce the storage life of the fruit. Hukill and Smith (25) estimated that a delay of 1 day at 70° F. may cause as much ripening as would occur in 10 days at 30°, and according to Smock and Neubert (58) the storage life is reduced about a week for each day of delay in getting the fruit into 32° storage.

Gerhardt and Smith (14) found that Delicious apples stored immediately after harvest at 31° F. had acceptable dessert quality in April while fruit that had been held 4 days at 65° before storage and then stored at 36° had become mealy in texture and stale in flavor by December. A delay of 10 or 20 days at 78° before placement in cold storage has been reported to reduce scald in Rhode Island Greenings, but off-flavors developed in most cases (43). In a report

1/ Underscored numbers in parentheses refer to Literature Cited, p. 80.

from Poland less breakdown was found to occur in fruit that had been held at higher temperatures prior to cold storage than in fruit that had been placed in cold storage immediately after harvest (3). It has been reported too, that a delay in storage of susceptible varieties may result in an increase in scald or bitter pit (58). Delays in storage also have been found to reduce the quality of Granny Smith (32), Sturmer Pippins (33), and Golden Delicious apples (47).

Storage of Jonathans at 36° F. for the first 6 weeks and than at 32° was found to reduce the incidence of soft scald in this variety (21). Tindale (63) reported the reduction of low temperature disorders in susceptible varieties if the fruit were stored initially at 38° and the temperature reduced gradually, in steps, to 32°. Padfield (35), however, in his investigations found a progressive reduction of the storage temperature from 38° to 32° to be no better than continuous storage at 37° to 38° for Jonathan, Ballarat, and Sturmer varieties. Stevenson (62) found fruit of the Granny Smith variety to be firmer and to be less affected by core flush if held at 36° than if held at 32° or 34° F. In their studies Guzewska, et al. (20) found continuous storage at 0° C. (32° F.) to be better for most of the 11 apple varieties they tested than a gradual reduction of the storage temperature from 8° to 0° C. (46.4 to 32° F.) or continuous storage at 4° C. (39.2° F.).

Storage Temperature

In studies where storage temperatures below 32° F. were tested Hall (21) found Delicious apples in New South Wales stored better at 30° than at 32°. Phillips (40) concluded from his tests that the storage life of apples can be increased by storing at 30° instead of 32- or higher. Phillips, et al. (42) later reported flavor of McIntosh to be acceptable for 6 months when stored at 30° or 31°, for 5 months at 32°, and for only 3 months at 33° F. Sako (55) reported from Finland that fruit of the varieties Atlas and Lobo when stored at -1° C. (30.2° F.) were as firm, and fruit of the Akero variety were firmer in April than fruit of the same varieties in November when stored at 4° C. (39.2° F.).

In an attempt to control low temperature injury of apples in storage at 0° C. (32° F.) Smith (56) interrupted the cold storage regimen of the fruit at periodic intervals, subjected the fruit to a 5-day warmup treatment at 15° C. (59° F.), and then returned them to 0° C. (32° F.) storage. He found fruit so treated after 6 and 8 weeks' storage at 0° C. (32° F.) developed less low-temperature injury than fruit treated after shorter or longer storage periods, or continuous storage at 0° C.

From studies on the influence of temperature on the rate of acid loss in McIntosh apples, Poapst and Phillips (46) developed an equation that may be useful in estimating the storage life of apples. Their data suggests that the rate of loss of total acid in McIntosh apples varies exponentially with the storage temperature.

Methods of Cooling

Several methods of cooling apples have been tested. Blanpied (1) found hydrocooling most rapid, tunnel cooling less rapid, and forced air refrigerated storage room cooling least rapid of these three methods. In fruit cooled by these methods he found greater variations after 5 months' storage between fruit

within a treatment than he did between treatments. In comparing fruit cooled by these relatively rapid methods with fruit that was cooled from 67° to 32° F. in 20 days, he found the fruit that took 20 days to cool was slightly softer than the more rapidly cooled fruit. Sainsbury (52) found tunnel cooling greatly reduced the time required to cool apples over the room cooling method. Phillips (38) described a forced-air circulation unit which cooled apples from 68° to 40° in 75.1 hours compared to 240 hours required where cooling relied only upon convection air currents in the storage room. Vacuum cooling of apples has been found unsatisfactory as a cooling method for apples because of desiccation or wilting of the fruit with resulting darkened or sunken areas (7, 8, 13, 27). See also (15, 19, 50, 64).

Phillips (41) found the cooling time could be reduced from 87 to 24 hours by maintaining a 10-degree differential between the storage room air and the mean fruit temperature throughout the cooling period.

Air Movement and Humidity

In studies on the effect of air movement and humidity on the cooling rate and moisture losses in apples, Dewey (7) found Golden Delicious took about twice as long to cool in still air as in moving air. In air at 1° to 2° C. (33.8-35.6° F.), Golden Delicious took approximately 5 hours to cool from 25° C. (75.2° F.) to 2° C. (35.6° F.) in still air and 2 1/4 hours and 2 3/4 hours in air moving at a rate of 770 and 385 f.p.m., respectively. He reported cooling was equally good in air of 70 or 90 percent relative humidity and found moisture losses to be too small to be considered significant. Greater water loss from apples in a storage with a blower in operation than in a storage without a blower operation has been reported by Christopher, et al. (4). Zahradnik (66) found no differences in firmness between apples from a storage with continuous blower operation and those from a storage in which the blowers were programed to operate only when the thermostat called for refrigeration. Comin, et al. (6) previously reported water loss from apples to be no greater with forced-air draft than with gravity flow, provided the relative humidity was maintained between 85 and 90 percent.

With increased ventilation in either regular or CA storage Hall, et al. (22) reported a reduction in scald on Granny Smith apples. (See sections on scald and volatiles.)

The efficiency of the air distribution systems of cold storages also plays a role in cooling fruit. A survey of fruit storages in Canada (16, 17, 18) revealed that more air distribution systems suffered reduced efficiency from poor air returns than from any other single factor. Placement of storage containers directly on the storage room floor has been shown to be undesirable as well, because the transmission of ground heat through the floor caused the bottom layer of fruit to have a higher equilibrium temperature than layers above it (51). (See also 25, 26, 49, 53, 57.)

Containers and Stacking Patterns [2]

The rate at which apples cool is affected by the nature of the storage containers, packing materials and stacking pattern. Fisher (10) found apples

2/ See also section on Shipping Containers.

in cardboard containers could be cooled as rapidly as apples in standard wood boxes if adequate spacing were provided. He (11) later reported that apples packed in containers that were stacked solid on pallets took twice as long to cool to 32° F. as apples in similar containers stacked loosely; the equilibrium temperature of the fruit in the solid stack was 1/2 degree higher than it was in the loosely stacked load. Olsen, Patchen, and Schomer (31) found proper spacing of stacks of fiberboard boxes of apples to be the most important factor in satisfactory cooling. Herrick, et al. (24) and Patchen and Sainsbury (37) found that apples stored in pallet boxes cooled as well as or better than those stored in standard boxes on pallets. For adequate cooling of apples in pallet boxes it has been suggested (24, 36, 37) that 8 to 11 percent of either the side or bottom of the pallet be vented, that the pallet boxes be stacked parallel to the airflow, and that a 4- to 6-inch air space be provided between rows and a 6-inch space along all walls.

Fisher and Smith (12) reported that apples placed in storage as they came in from the orchard, in open bushel baskets without any packing materials cooled to 32° F. from 63° in 18 hours while it took 10 days for apples to cool from 70° to 32.5° when they were packed in lined baskets with a pad under the lid and shredded oiled paper distributed throughout the container. (See also 5, 9, 23, 29, 30, 54, 59, 61.)

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CONTROLLED-ATMOSPHERE STORAGE

CA Storage Research Around the World

The principles upon which controlled-atmosphere (CA) storage (gas storage in England) is based were applied to the storage of apples in England by Kidd and West over 30 years ago. By 1939 there were over 4.5 million cubic feet of gas storage facilities in England according to Kidd and West (43). [1/] CA storage of apples in the United States got its start on a commercial basis with McIntosh in the Hudson Valley in the early forties. In December of 1962 the International Apple Association (1) reported nearly 8.5 million bushels of apples in CA storages in the United States and 884,770 bushels in CA storage in Canada.

Research on the CA storage of apples has been carried out in many countries to determine the conditions that may extend the storage life or maintain the quality of the fruit better than normal air cold storage.

England

Kidd and West (43) in 1950 summarized the CA (gas storage) requirements of 15 English-grown apple varieties on which they had conducted investigations

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1/ Underscored numbers in parentheses refer to Literature Cited, p. 94.

over the years. Based upon the storage conditions to which these varieties were best suited, they classified them into 3 groups: (1) Those which respond best in an atmosphere where the CO_2 and O_2 levels total 21 percent, (2) those which respond best in an atmosphere where the CO_2 and O_2 levels total less than 21 percent, and (3) those which will not tolerate CO_2 and should be stored in air. They placed Bramley's Seeding in the first group, suggesting an atmosphere of 9 percent CO_2 and 12 percent O_2 at 40° F. Cox's Orange Pippin was placed in the second group as it responded more favorably in an atmosphere of 5 percent CO_2 and 2.5 percent O_2 at 34°. Newton Wonder and Blenheim Orange were two varieties for which they recommended air storage. West (103) further pointed out that CO_2 levels of 13 percent or more were liable to injure the fruit. This injury was referred to as brown heart but now is generally called CO_2 injury. To reduce the likelihood of scald injury in gas storage they suggested the use of scald control measures, such as oil wraps, on those varieties susceptible to this disorder.

Canada

Reports on CA storage in Canada indicate that McIntosh may be stored from 34° to 40° F. in atmospheres of 5 percent CO_2 and 2.5 to 3 percent O_2 or 7 percent CO_2 and 14 percent O_2 (72, 79, 21, 29). Core flush (brown core), which develops in McIntosh stored at 30° to 32° F., is controlled by the higher storage temperatures. CA storage at these higher temperatures more than compensates for the shortened storage life that would otherwise occur at the higher temperatures. Eaves (21) and Phillips and Poapst (77) found the 7 percent CO_2 and 14 percent O_2 mixture as good as or better than the 5 percent CO_2 and 3 percent O_2 mixture for McIntosh particularly where scald is not a problem (77). However, Phillips and Poapst (75) found the occurrence of scald to be more likely in the 7 percent CO_2 and 14 percent O_2 atmosphere than in the lower CO_2-O_2 mixture. On Cortland, Phillips and Poapst (74) found different O_2 levels had no effect on scald. The best control of scald on Cortland in CA storage was obtained with DPA (Diphenylamine) dips (73).

In one study Phillips and Poapst (76) observed an unusual number of sprouted seeds in a lot of McIntosh that also had core flush. In an experiment to test the effect of CA storage conditions on seed germination, they found that conditions which most effectively reduced core flush also had the greatest inhibitory effect on seed germination. They suggested that this information may be of use to determine whether a given lot of fruit had or had not been stored under CA conditions.

Australia

In their studies on Australian apples, Huelin and Tindale (38) found three of eight varieties tested responded favorably to CA storage. They recommended an atmosphere of 5 percent CO_2 and 16 percent O_2 for Jonathan, Democrat, and Granny Smith. They suggested a storage temperature of 31° to 32° F. for the last two varieties but for Jonathan they suggested 36° the first month, 34° the second month, and 32° for the rest of the storage period. These conditions controlled Jonathan spot and soft scald, but some breakdown and brown heart did occur in the Jonathans. Scald was controlled on Jonathans by oil wraps but even these did not always provide control of scald on Granny Smith. Hall (35) found

a 1.5 percent O_2 atmosphere at 32° significantly reduced scald in Granny Smith and DPA controlled it in all treatments. In a later publication Scott, et al. (83) reported that an atmosphere of 5 percent CO_2 with 2.5 percent O_2 was most suitable for long storage of Granny Smith apples grown in New South Wales.

Hall, Scott, and Coote (36) reported scald on Granny Smith to be controlled by DPA in air, CA, or polyethylene liners. Stevenson (93) found scald on this variety to be related to the amount of CO_2 in the atmosphere and to be less severe on more mature fruit. Stevenson (93), testing Granny Smith, found a 5 percent CO_2 and 16 percent O_2 atmosphere to be better than air storage for this variety. Subsequent reports (94, 95, 96) on Granny Smith have indicated that this atmosphere was satisfactory, but a treatment, such as a DPA dip, was necessary to control superficial scald. Hall and Sykes (34) reported an atmosphere of 5 percent CO_2 and 16 percent O_2 was better than air for the storage of Jonathan apples. Hall and Sykes noted too that more than 3 percent CO_2 was required to control Jonathan spot. McGlasson and Jacobsen (53) found a 5 percent CO_2 and 3 percent O_2 atmosphere at 32° F. was superior to air storage for Jonathans. Huelin and Tindale (38) found that the Democrat variety not only responded well to CA storage, but it appeared to undergo an improvement in quality as well, as a result of such treatment.

According to Martin and Cerny (51) storage of Tasmanian apples in atmospheres low in O_2 and in the absence of CO_2 at 31° to 32° F. is superior to storage in air or in 5 percent CO_2 and 16 percent O_2. Better texture and quality were maintained, less breakdown, scald, and core flush occurred, but Jonathan spot was not controlled as well as in an atmosphere containing CO_2 though it was less severe than it was in air. These authors suggested at this time an atmosphere of 3 percent O_2 at 32° as one most suitable for all Tasmanian apple varieties. Martin (52) later reported control of scald on Granny Smith in an atmosphere of 5 percent CO_2 and 16 percent O_2, by first passing the fruit through steam arising from boiling water which contained at least 0.5 percent DPA. Three 10-second passes were especially effective.

New Zealand

Mandeno and Padfield (48) found Jonathan spot to be negligible on New Zealand Jonathans after storage in atmospheres of 3 to 9 percent CO_2. However, in 8 percent CO_2 or more at temperatures of 40° F. or above. brown heart and a form of deep scald were likely to occur. By storing Jonathans in an atmosphere of 7 percent CO_2 and 14 percent O_2 at 40° to 41° and a relative humidity of 90 percent, they were able to extend the storage life of this variety 2 months beyond that obtainable in ordinary cool storage. They report, too, that increasing amounts of CO_2 retarded softening and slowed color changes. With Granny Smith they found no consistent effect of CO_2 level on occurrence of scald, but on Sturmer they found a direct relationship between the O_2 level and scald at 35°. At 35° scald was lowest in the low O_2 atmosphere while at 41° the incidence of scald was not affected by the O_2 level. Padfield (58) later reported atmospheres of 2 to 5 percent CO_2 and 3 to 5 percent O_2 provided advantageous storage conditions for 5 of 10 apple varieties tested.

Denmark

CA storage trials in Denmark are reported by Dullum and Rasmussen (20) in some detail and summarized for the 8th International Congress of Refrigeration by Rasmussen (81). A number of the apple varieties in Denmark responded most favorably to a gas mixture of 8 to 10 percent CO_2 and 11 to 13 percent O_2 at 39° to 40° F. Jonathan may show some CO_2 injury under these conditions and Boikin and Bramley's Seedling may develop scald. Belle de Boskoop and Cox's Orange Pippin are injured by CO_2 concentrations much above 5 percent so for these varieties a mixture of 5 percent CO_2 and 2 to 3 percent O_2 at 39° to 40° F. is suggested.

The Netherlands

The gas storage conditions in use in the Netherlands are similar to those of Denmark. Van Hiele (101) details these conditions as being 10 percent CO_2 and 10 percent O_2 for Bramley's Seedling and Golden Delicious; 5 percent CO_2 and 4 percent O_2 for Cox's Orange Pippin; and 7 percent CO_2 and 13 percent O_2 for Jonathan. All of these to be stored at 4.5° C. (40° F.).

Norway

Of five varieties tested by Lanfald (44) in Norway, the variety Filippa responded most favorably to CA storage. The best storage conditions for this variety were 5 percent CO_2 with 3 percent O_2 at 1° C. (33.8° F.). His results with Gravenstein, Bramley's Seedling, and James Grieve were not striking. The atmospheres tested did retard ripening, but the occurrence of scald and brown core largely offset the beneficial effects.

United States

A December 1961 issue of the International Apple Association's Special Letter (2) lists eight varieties of apples in CA storages in the United States. In order of decreasing volume these varieties were McIntosh, Delicious, Newtown, Jonathan, Rome, Northern Spy. Golden Delicious, and Stayman. These varieties are stored in atmospheres that range from 1.5 to 5 percent CO_2 and 2.5 to 3.5 percent O_2. Specific recommendations for the varieties and conditions in their areas may be found in publications by Smock (88), Van Doren (100), Southwick and Zahradnik (92) and Dewey, et al. (18). Research to establish these CA requirements has been carried out by a number of investigators.

Smock (86) at one time recommended an atmosphere of 5 percent CO_2 and 2 to 3 percent O_2 at 40° F. for the CA storage of McIntosh. In 9 out of 10 years these conditions entirely prevented the development of brown core (core browning, core flush), a low temperature disorder of McIntosh. Smock later (88) revised this to 38° to 40° with the O_2 level unchanged but with a CO_2 level of 2 to 3 percent for the first month to be followed by the 5 percent level. This change in the CO_2 level was to avoid the occasional external CO_2 injury that may occur during the early storage period when the fruit is apparently more susceptible to external injury. Southwick and Zahradnik (92) have not found Massachusetts McIntosh to be injured by the 5 percent level of CO_2, and they suggest this concentration throughout the storage period.

The low temperature disorder, internal browning, of Yellow Newtowns does not develop at 40° F. or above according to Allen (8). By adding CO_2 to the atmosphere then, he found the ripening rate could be reduced to a level comparable to low temperature storage and so extend the storage life of this variety. A more recent work by Van Doren (100) lists the CA requirements for Yellow Newtowns as 5 percent CO_2 and 3 percent O_2 at 38° F.

Smock has reported that a delay in putting harvested fruit into CA storage greatly reduces the beneficial effects of CA storage (85).

CA Storage Effects on the Fruit

Fruit Quality

Budiselich (13) and Van Doren (99) found an atmosphere of 0 to 0.5 percent CO_2 and 2 percent O_2 kept Red and Golden Delicious in marketable condition through May. This finding agreed with the findings of Fisher (28) with respect to CO_2, for he found an atmosphere containing CO_2 hastened the onset of mealiness in Red Delicious. Schomer and Sainsbury (82) in 1957 also reported that, even with low levels of CO_2, Red Delicious apples stored in low oxygen atmospheres maintained a better appearance and texture than fruit stored in air. However, they reported a loss of its characteristic flavor. On Gravenstein too, Allen and Torpen (9) have found that although color development and softening are retarded the aroma and flavor are lost in CA storage as quickly as or more quickly than in air storage. Okamoto and his coworkers (56, 57), reporting on CA storage of apples in Japan, found the acidity of apples from CA remained higher, sugar loss was less, and firmness was greater than in apples from ordinary cold storage. Blanpied and Dewey (11) found that differences in the quality of McIntosh stored in air and controlled atmospheres did not become apparent until the fruit had been in storage about 100 days. From that time on, the superiority of the CA fruit became increasingly more pronounced. Off-flavors were reported to develop in McIntosh when the CA storage temperature was gradually lowered (87) or when held continuously at 32° (12).

Jonathan Spot and Soft Scald

Jonathan spot is controlled in an atmosphere containing 2.5 percent or more of CO_2 according to Ballinger (10) and in 3 percent or more CO_2 according to Hall and Sykes (33). Both papers report also, that the fruit remained free or nearly free of soft scald in CA storage. On Michigan-grown Jonathans, Ballinger (10) found the best storage conditions to be 5 percent CO_2 and 3 percent O_2 at 32° F. Subsequent work on Jonathans by Dewey, Ballinger, and Pflug (18) confirmed these conditions as giving the best control of Jonathan spot, near elimination of soft scald, as well as maintaining the quality of the fruit better than any other set of conditions tested. Varying degrees of success in controlling Jonathan spot and prolonging the storage life of Jonathans by CA storage have been reported by several other research workers (16, 38, 81, 101, 102).

CO_2 Injury

Injury from CO_2 (brown heart) has been reported to occur on a number of apple varieties. Carne (14) in 1948 described brown heart as being caused by a concentration of CO_2 in the storage atmosphere in excess of a critical limit which varies depending upon the variety, temperature, and maturity of the fruit. Martin and Carne (50) reported that Sturmer apples could be injured by as little as 3 percent CO_2 and Jonathan by a 12 percent level. They also found more mature fruit, to a point, to be more susceptible to CO_2 injury and the injury generally to be more severe at 33° F. than at 38° to 43°. Dewey, et al. (18), however, found considerable CO_2 injury on Michigan Jonathans in 2.5, 5, or 7 percent CO_2 levels at 40°, less injury at 36°, and only slight injury in the 7 percent CO_2 atmosphere at 32° F. Mandeno and Padfield (48) also have found CO_2 injury in Jonathans occurred at levels of 8 percent or more when stored at 40° F. or above. On McIntosh, in his studies of brown core, Smock (84) did not find that high levels of CO_2 aggravated the development of this disorder at 32° or 36°, but at 40° such levels of CO_2 when accompanied by relatively high O_2 concentrations did seem to cause an increase in brown core.

Hulme (39) associated CO_2 injury in apples with the accumulation of succinic acid. Fruit were injured more readily at 37° than at 50° F. Apples stored in 20 percent CO_2 at 37° contained 21 mg. of succinic acid per 100 gm. of fruit, and the fruit showed CO_2 damage. Fruit stored at 50° contained only 1.10 mg. of succinic acid, and no visible injury was apparent. Nyhlen (55) studied CO_2 injury in apples from a nutritional and environmental standpoint. He found damaged fruit had a high potassium and low phosphorous content. Soil analyses also showed a high K_2O/P ratio. The contents of boron and manganese did not appear to be related to the damage.

In an evaluation of the separate effects of CO_2, O_2, and temperature on McIntosh in CA storage, Blanpied and Smock (12) reported that firmer fruit with less scald was associated with low temperatures, low O_2, and high CO_2 levels. Also less external CO_2 injury was found to occur at 32° than at 36° or 38° F.

Scald

A number of investigators have reported that low levels of O_2 tend to reduce the development or severity of scald (48, 51, 60, 61, 85, 88). Others, however, have failed to show that the level of O_2 has an effect on the development of scald (74) or that the mixture of CO_2 and O_2 has affected this disorder in any way (82).

The results on the effects of CO_2 on scald have likewise been somewhat variable. Stevenson (93) found less scald in low CO_2 atmospheres on early maturity fruit, but on later maturity fruit less scald occurred in a higher CO_2 atmosphere. Phillips (78), Martin and Cerny (51), and Hall and Sykes (34) found scald to be greater in atmospheres containing CO_2 or in increasing concentrations of CO_2. Mandeno and Padfield (48) found no consistent effect of CO_2 levels on the development of scald but did find scald greater at 36° and 38° than at 34° F. Patterson (60) and Patterson and Workman (61), on the other hand, found increasing levels of CO_2 delayed scald. Budiselich (13) observed scald on all his treatments except the 5 percent CO_2 and 2 percent O_2 treatment.

The extent to which apple volatiles accumulate in CA storages and the effects these volatiles may have on the stored fruit (scald particularly) are reported in a number of publications. Fidler (26) found the concentration of

ethylene greatly exceeded that of the nonethylenic volatiles in gas storages. He later reported (27) that gas storage conditions reduced the rate of evolution of volatiles from the fruit. Johansson (40) found the ethylene concentration to range from 24.2 to 30.7 mg. per cu. ft. of storage atmosphere in a 1,400-bushel CA room filled with McIntosh. Potter and Griffiths (80) found the rate of evolution of volatiles to be reduced in an atmosphere of 10 percent CO_2 and 5 percent O_2. Meigh (54) found all volatiles to be produced at a greater rate in air than in gas storage. Potter and Griffiths (80) also found that when the O_2 level was reduced to 5 percent at 15° C. (59° F.) ethylene production was greatly increased for the first 40 days, and its subsequent decline was more rapid than in air at the same temperature. At the same time the odorous fraction was correspondingly reduced. Meigh (54) found no correlation between the high rate of evolution of volatile substances of some apple varieties and the development of scald. Fidler (27) filtered the volatiles from the atmosphere but still could not control scald as well as oil wraps could in an unfiltered atmosphere. Southwick (91), however, found scald to be more severe in a year when volatile production was greater. This was also reported by Griffiths and Potter (31) in their work on King Edward apples. Indications that volatiles are implicated in scald development are also contained in a work by Hall, Scott and Riley (37), who found scald was reduced by increased ventilation in either regular or gas storages. The effects of ethylene on respiration of apple fruits in gas storage was found to be quite variable by Griffiths and Potter (32). The respiratory activity of some fruits was decreased and that of others was increased.

Modified Atmospheres in Plastic Film

Much work has been done with plastic films as storage containers for apples and other produce. This type of material, when left unperforated, modifies the atmosphere surrounding the commodity. However, the atmosphere is not controlled, and this may prove to be very undesirable as low O_2 or high CO_2 levels may develop and injury occur. Smock and Blanpied (89), in comparing CA storage and film liners for storage of apples, concluded that CA storage was safer than sealed film liners were.

Chace, Dewey, and Pflug in 1957 (15) reported the results of a test in which vinyl plastic film was used to form a "tent" within a regular cold storage room. This tent held 2,460 bushels of McIntosh apples and satisfactorily maintained an atmosphere of 5 percent CO_2 and 3 percent O_2 for a 6 1/2 months' storage period. Eaves (22, 25) also investigated the possibilities of using plastic CA storage units within an existing cold storage room. He describes construction, operations, and costs of a 1,000 box unit. Three similar units were successfully operated during the 1959-60 season.

Significant contributions on the use of plastic films as storage containers for fruit have also been made by Eaves (24), Leblond (46) and Tolle (97). These and related subject material are discussed in greater detail in the section "Film Box Liners and Pallet Covers."

Other Factors Affecting CA Storages

Operation and Maintenance of CA Rooms

A number of publications are available that provide practical instructions for the operation and maintenance of CA storages: Smock (86, 88), Phillips and Poapst (72, 77), Van Doren (100), Huelin and Tindale (38), Kidd and West (43), Southwick and Zahradnik (92), Pflug and Dewey (69). These publications also discuss in varying degrees the design and construction details of a CA storage room. This includes methods of making a room gastight, the need for an outer vapor seal to prevent water from condensing in the insulation, and methods of testing a room for gastightness, as well as such special equipment, needed to operate a CA storage, as CO_2 absorbers and gas analyses apparatus.

Attempts have been made to develop methods and utilize materials that are less costly than the masonry and metal storage structures in general use, but that would adequately meet the requirements of a CA storage. Pflug, Brandt, and Dewey (68) had an 800-bushel CA storage built of precast concrete wall slabs. The room served as a satisfactory CA storage but gusty winds at times caused an increase in the oxygen level of the storage atmosphere of 0.2 to 0.3 percent in a 24-hour period. In a 1958 bulletin, Zahradnik and Southwick (105) detailed the design, construction, and performance characteristics, and the costs of an all-plywood CA storage. Their results indicate that this type of construction would serve adequately as a CA apple storage room. Layer (45), in a 1962 article, briefly discusses current construction of CA storages.

Related research has been concerned with factors that affect the maintenance of the room atmosphere. Pflug and Southwick (62) developed a method for measuring the leakage rate of a CA room and devised a way of reducing it by the use of a vinyl plastic breather bag. The breather bag reduces air leakage due to temperature cycling but does not reduce leakage from a pressure differential induced by evaporator fans, wind, or changing barometric pressures (63, 64). Pflug and Dewey in 1956 (65) presented an equation relating air leakage, respiration rate, room fullness, and oxygen equilibrium level for a CA storage. Zahradnik, Southwick, and Fore (104) found that improperly designed circulation within a CA storage with accompanying high atmosphere velocity may cause differential pressures within the room, which in turn may result in an increased leakage rate.

CO_2 Scrubbers

A number of different methods have been devised to remove the carbon dioxide from CA storages. The atmospheric washer, CO_2 absorber or scrubber, as it is variously called, originally used calcium or sodium hydroxide in solution as the CO_2 absorbing agent (43). In 1957, Pflug, Angelini, and Dewey (66) reviewed the fundamentals of CO_2 absorption in discussing three of the most commonly used absorbers: the barrel-type designed by Smock and Van Doren, the brine-spray type of Kedenburg (42), and the packed-tower of Pflug, et al. (67). Eaves (23) developed a dry scrubber that uses dry hydrated lime. Simply by passing the CA atmosphere over these bags, he was able to maintain the CO_2 level as low as 0.8 percent. A solution of mono-ethanolamine has been used by Mann (49) to absorb CO_2. This solution can be regenerated by heating and reused, thus eliminating the need for recharging the absorber.

During the 1957-58 season, Palmer (59) found that a caustic soda solution was not required to maintain a 5 percent CO_2 level in his CA rooms. The water circulated through the brine-spray unit in a CA room was being aerated in the work space outside the room, and there was enough gas exchange of CO_2 into the brine while it was in the CA room and out of the brine in the outside air to maintain the desired CO_2 level. Subsequent to Palmer's observations, detailed tests were performed to evaluate the usefulness of water as an absornent of CO_2. Smock and Yatsu (90), concentrating their study on methods of aeration, reported the most efficient system involved the use of a packed tower with counter-current airflow. In 1960, Pflug (70) presented a procedure for calculating the rate of O_2 reduction in a CA room and used it to compare the reduction rate when caustic soda and water CO_2 absorbers were employed on rooms of several degrees of fullness and leakage rates. He found that only 2 to 3 days of additional time was required for a tight CA room to develop a 3 percent O_2 level with a water absorber in place of a caustic soda absorber. In later work, Pflug (71) describes the design and operating characteristics of a single tower water absorption-desorption system for removing CO_2 from a CA storage. Uota (98) in 1961 described a laboratory scale water scrubbing system for controlling CO_2 levels in CA chambers. By regulating the flow rate of water through the exchanger, a relatively close control of the CO_2 levels was possible.

Costs

Loudon and Zuroske (47) reported in 1953 that the cost of storing Washington Red Delicious apples in a CA storage would be from 45 to 50 cents per box per season, or approximately 20 cents more per box than for ordinary cold storage. This estimate was based on conversion of existing cold storage facilities to a CA storage. Dalrymple (17) estimated in 1956 the cost of building a CA storage of 12,000-bushel capacity to be \$2.75 per bushel, or 50 cents more per bushel than a regular cold storage, and the cost of converting an existing cold storage of 12,000-bushel capacity to a CA storage to be 50 cents per bushel. He also estimated the cost of storage in CA to be about 50 cents per bushel per season, which he estimates is about double the cost of refrigerated storage. Dewey (19) reported the estimated cost of CA storage to be 50 cents per 40 pounds of fruit. Southwick and Zahradnik (92) estimated the cost of converting a regular cold storage to CA to be \$0.80 to \$1.50 per box and that of a new structure to range from \$2.25 to \$3.50 per box. In an attempt to reduce the costs of constructing a new CA storage, Zahradnik and Southwick (105) found that a 7,000-bushel capacity CA storage could be built of plywood at a cost of \$2.20 per box. By using their own workers to help in the construction, Greimer (30) and Johnson (41) reported costs of \$1.75 and \$1.76 per bushel for building their own CA storages.

Regulations

Several States have adopted regulations governing the operation of CA storages. New York was the first to do so. California (4), Michigan (5, 6), and Washington (7) also have such laws. They are similar to the New York law (3) which requires, in part, the annual registration of the rooms by the owner or operator of such rooms, that the room atmosphere meet a minimum O_2 concentration of 5 percent within 20 days of sealing (30 days in Michigan), and that the fruit to be called CA fruit must be held in an atmosphere with not more than

5 percent O_2 for a minimum of 90 days (Michigan allows this minimum to be 60 days for Jonathan apples). The Washington law allows 25 days to reach the 5 percent O_2 level if other fruits or vegetables are stored in the CA storage. Washington also specifies condition and maturity standards for CA apples. In addition, operators of CA storages are required to keep a daily record of the gas analyses of each CA room.

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VOLATILES AND ATMOSPHERE PURIFICATION IN STORAGE 1/

Many studies have been made on the effects of volatiles in apple storages. Much of the research and thought on the role of ethylene and nonethylenic volatiles produced by fruit is reported in the reviews of Biale (3), Burg (10), Pentzer and Heinze (57), Porritt (62), Ulrich (83), and Varner (88) as well as in a number of publications concerned with volatiles and air purification studies (13, 16, 25, 28, 47, 71, 74).

The results of air purification investigations on apple quality have not been in agreement. According to some reports, the removal of storage volatiles may extend the storage life, decrease the rate of softening, or improve the flavor or appearance of the fruit (61, 69, 70, 72, 78, 85, 86, 87). Others, however, have not observed such benefits to accrue as a result of air purification (17, 21, 23, 24, 89). It was later suggested that air purification could be beneficial only if the fruit were in the preclimacteric stage of development (47, 74).

Though volatiles given off by postclimacteric apples have been credited with stimulating respiration and ripening, investigations at temperatures near those normally used for apple cold storage have shown ethylene or the vapors from ripe apples to have little or no stimulatory action on respiration or ripening (19, 20, 26, 30, 56, 75).

Volatiles have been implicated in the development of scald in a number of reports (31, 47, 68, 69, 70, 73, 78) but they have been found to have played little or no role in its development in a series of other investigations (17, 23, 24, 39, 49, 55, 56, 89). Smock (74) concluded in 1955 that "Scald control with any air purification agent is inadequate." The relationship of ethylene

1/ Underscored numbers in parentheses refer to Literature Cited, p. 104.

to scald has been reviewed by Porritt (62) and that of ethylene and nonethylenic volatiles to scald by Pentzer and Heinze (57). (See also section on Scald.)

For the removal of volatiles and other odors in air purification studies, activated carbon has been used to a considerable extent (17, 32, 35, 42, 69, 77, 82, 84). However, activated carbon has been found to be ineffective as an absorbent for ethylene (12, 22, 23, 24, 42, 54, 59, 60, 77). Brominated activated carbon absorbs both ethylene and nonethylenic volatiles (18, 23, 77), but its efficiency decreases rapidly and it is very corrosive (18).

Ozone (12, 18, 32) and chlorine (18, 32) have also been used for air purification. Though both reduce the volatiles present, ozone may injure the fruit (18, 67) and chlorine may produce off-flavors and cause the fruit to develop a poor appearance (18).

The use alkaline potassium permanganate has been suggested for the removal of apple storage volatiles (43, 44), but in at least one investigation (89) in which it was used it failed to reduce the level of volatiles, did not reduce scald, nor delay softening of the fruit in storage.

Scrubbing the storage atmosphere with water has been found to effectively remove fruit volatiles by some (1, 42) but not by others (4, 15). The negative results were obtained in storage atmospheres having a very low ethylene concentration to begin with. In an earlier report Grierson-Jackson (29) pointed out that water condensing on the refrigeration coils of cold storage rooms may remove volatiles; in air purification tests, therefore, it is important to specify the type of refrigeration in use in the rooms under study.

Many compounds have been identified in apple volatile emanations. These are summarized in the reviews cited (57, 83), in a report on apple biochemistry (41) and in several papers concerned with the volatiles given off by apples or occurring in apple storages (16, 35, 36, 37, 49, 50, 51, 79).

Methods used in the analyses of apple volatiles have included biological assays (primarily for ethylene) (14), combustion (64), and oxidation with ceric, permanganate, or chromic reagents (22, 33, 16, 64). Partition chromatography (35), paper chromatography, and spectrophotometry have also been used (38, 49, 50) as has mass (37) and infrared spectrophotometry (39, 81). More recently gas chromatography has been used to determine ethylene (7, 8, 51, 52, 53), as well as other volatiles (28). In addition to details provided in these reports, the articles by Burg (11) and Meigh (48), and the reviews of Porritt (62), Burg (10), and Ulrich (83) discuss the older as well as the newer methods used in analyses for ethylene or nonethylenic volatiles.

Research on apple volatiles has included measurements of the rate of production of these volatiles (23, 25, 34, 58, 80) and estimates of the volatile levels that might be found in apple storage rooms (4, 15, 63, 66). One such estimate (66), based on the analyses of the atmospheres of 30 commercial storage rooms, gave a range in concentration for ethylene of 2 to 100 ppm and for nonethylenic volatiles of 2 to 20 mgs. per cu. ft. (expressed as mgs. $Ce(SO_4)_2$ reduced).

In controlled atmosphere storages (CA or gas storage) the production of volatiles by apples is reportedly reduced (50, 63, 75, 76). Though production of volatiles is reduced, the concentrations developed within the CA storage room may be greater than that occurring in a regular cold storage because of the gastight room (unless provisions for volatile removal have been made). Fidler (18), for example, found ethylene levels ranged from 50 to 400 ppm in some of his gas storage studies. Fidler also reported (16) that the concentration of ethylene always exceeded that of the other organic volatiles in gas

storage, estimating ethylene to constitute 70 to 80 percent of the total volatile output (20). Other researchers have also found ethylene to be produced in far greater amounts than the nonethylenic volatiles (40, 51).

In their studies on the physiology of ethylene formation in apples, Burg and Thimann (8) found the optimum temperature for ethylene production to be 32° C. (87.8° F.), above which it fell rapidly. Southwick (76) reported in 1945 that McIntosh apples held at 32° F. emitted about half as much volatile material as similar fruit held at 40°.

In apple tissue experiments, decreasing the oxygen concentration to 2.5 percent resulted in a 50 percent reduction of both ethylene production and respiration, and under completely anaerobic conditions the production of ethylene ceased almost immediately (8). Increasing amounts of carbon dioxide decreased production of ethylene by apples (5).

Apples or parts thereof have been used in many experiments designed to learn something about the metabolic pathway or source of ethylene formation (2, 4, 6, 9, 45, 46). The results given in these papers along with the reviews previously cited (3, 10, 57, 62, 88) provide an adequate summary of the current status of research in the field of volatiles, particularly ethylene, as carried on with apples and other biological materials.

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RIPENING AND COMPOSITION

Ripening of apples involves the transformation of a hard nearly inedible object into a succulent delicious treat to the palate. Ripening may be confined entirely to the after-harvest period, or it may occur to some extent on the tree before harvest and be confused with maturation. However, maturation ends when the apple is harvested, and only ripening and senescence follow (77). Ripening involves changes in firmness and texture, color, flavor, odor, and composition. These changes are preceded by or begin with a rapid increase in respiration frequently referred to as the climacteric. Hulme (29) considers ripening as embracing all those processes which take place from the onset of the respiration climacteric until the fruit has assumed the color and texture at which it is normally consumed. [1/] The ripening processes continue beyond this point, however, causing overripeness and lead to reactions related to senescence. The activities in the ripening process are recognized as being largely enzyme mediated and involve various oxidative and glycolytic reactions.

Respiration and the Climacteric

Respiration in apples, like most chemical reactions, is sensitive to temperature and, within limits, increases in rate with rise in temperature. It is also sensitive to the concentration of oxygen and carbon dioxide as well as to the presence of other gases such as ethylene in the surrounding atmosphere. As the oxygen concentration is reduced and the carbon dioxide concentration increased from that in normal air, respiration is depressed. The presence of small quantities of ethylene may, under some conditions, induce an added increment to respiration, the climacteric. This is usually followed by a sequence of ripening processes. Kidd and West (39) indicated some years ago that the climacteric may occur while the fruit is still on the tree. It may be in progress during harvest or take place after harvest. A number of factors including variety, location, and climatic conditions appear to affect the timing of the climacteric. The use of the climacteric for determining the time to harvest is discussed under another section in this review entitled, "Harvest Maturity."

1/ Underscored numbers in parentheses refer to Literature Cited, p. 117.

Although relatively little is known about the biochemistry of the climacteric, some recent advances provide a partial understanding of its operation. Hulme (25, 28) and Turner (76) have shown that there is a net increase in protein nitrogen in the apple during the climacteric. It has also been observed frequently that the respiratory quotient exceeds unity during the climacteric, i.e., carbon dioxide evolved is greater than the oxygen consumed. Okamoto (53), Dilley (12), and Hulme and Wooltorton (32) have shown that a malic enzyme is operative in apple tissue and exhibits a steep rise in activity during the climacteric. Hulme, Jones, and Wooltorton (30) suggest that the origin of the climacteric is due to an increase in activity and a synthesis of malic enzyme and carboxylase, the energy for the synthesis being supplied by mitochondrial activity. They also indicated that a loss in malic acid content is rapid during this period. Malic acid may serve as a substrate for carbon dioxide production without utilizing oxygen. The synthesis of protein during the climacteric and the failure of others (30) to find any large scale uncoupling between oxidation and phosphorylation makes the uncoupling theory for the climacteric in the avocado as proposed by Millerd, Bonner, and Biale (51) untenable for apples.

Hartman (19) has also found maximum aldolase activity in apple tissue during the climacteric. This agrees with an earlier report by Tager and Biale (73) who found an increase in activity of aldolase and carboxylase during ripening of bananas.

Many of the enzymes involved in respiration are associated with subcellular cytoplasmic particles or mitochondria. Considerable difficulty has been encountered in isolating active particles from apple tissue because of the high acidity and the presence of phenolic compounds. However, with special techniques, a number of workers (20, 35, 43, 44, 52, 54, 72) have obtained preparations that oxidize various acids in the Krebs cycle and exhibit cytochrome oxidase activity. The possibility now exists that more of the basic mechanisms concerned with respiration and the climacteric may be understood by studying the activities of these particles or the sonicated particles at different stages of disintegration. Hulme and Wooltorton (32) have shown that low sonication times release more of the malic enzyme and carboxylase from the particles, whereas higher sonication times release more of the Krebs cycle enzymes. This suggests that some enzymes are more tightly bound than others.

Smock (63) has reviewed some of the earlier enzyme studies which dealt primarily with oxidase and catalase. A later more detailed review of the biochemistry of the climacteric is given by Hulme (28).

Size of apple is another factor that affects respiration. Sullivan and Enzie (71) noted that large apples respire more rapidly than small apples immediately after harvest and also after storage at 35° F. Caldwell (10) found an increase in partial pressure of oxygen was toxic to apple tissue at high pressures and that actual pressure itself was not responsible for disorganization of the cells. Twenty atmospheres of 5 percent oxygen had essentially the same effect on carbon dioxide production as one atmosphere of 100 percent oxygen. Barker (2) in a later report agrees with Caldwell in part but asserts that an absolute pressure of three atmospheres with oxygen remaining at 20 percent of one atmosphere inhibits carbon dioxide production to some extent and that this can be attributed to mechanical distortion of the tissue.

Woodruff and Crandall (82) screened 18 chemicals for their effect on inhibiting respiration in apple slices then tried the most promising on whole apples by injecting solutions into the core area. Solutions of sodium malonate, 3-indolepropionic acid, hippuric acid, and benzimidazole were most effective with a maximum reduction of about 10 percent in respiration of the whole fruit.

Smock et al. (64) found that N^6-benzyladenine stimulated respiration in the preclimacteric phase and depressed it about 10 percent in the postclimacteric period. No beneficial effects on the storage behavior was noted in the varieties studied.

Ethylene

The production of ethylene appears to be closely related to the climacteric, but its exact role remains obscure. Burg (6) has comprehensively reviewed the physiology of ethylene formation and its action in plant tissues and concludes that it participates as a hormone, stimulating ripening in perhaps all fruits. Biale (3) states that a climacteric induced by adding ethylene does not increase rates of respiration for the corresponding stages of the climacteric but merely shifts the time axis.

The temperature of apples at the time of ethylene treatment has considerable influence on the response. Fidler (15) found very little difference in untreated and treated apples during storage at 3° C. (37.4° F.). However, at storage temperatures of 7° and 12.5° C. (44.6 and 54.7° F.) the climacteric was induced earlier in ethylene-treated fruit. Gerhardt and Siegelman (16) measured the respiration, firmness, and soluble solids of apples stored at three temperatures (31°, 45° and 65° F.) and did not find any differences between those ventilated with fresh air and those exposed to emanations including ethylenic and nonethylenic volatiles of ripening apples. Very high levels of ethylene accumulate in controlled atmosphere storages (15, 59). Either ethylene has no effect on ripening under these conditions, or the effect is far outweighed by the modification of the oxygen and carbon dioxide content of the atmosphere surrounding the apples. Wilkinson (81) suggests that a separation of the climacteric and ethylene production, which are usually considered to be coincident, can be brought about by delaying harvesting until the fruit are in their climacteric on the tree. Under these conditions the ethylene production was found to lag considerably behind the rise in respiration.

Attempts have been made to determine the origin of ethylene in apple tissues. Burg and Thimann (8, 9) have studied the effect of various solutions and inhibitors on ethylene production of apple slices. They have also found that the application of labeled glucose to the slices is followed quickly by the appearance of labeled carbon dioxide and, after a slight lag, by labeled ethylene. Burg and Burg (7) found that apple tissue could convert labeled triose into ethylene, but the efficiency was unexpectedly low in comparison to glucose. These and other studies led to the suggestion that ethylene may be produced by mitochondria or cytoplasmic particles. Lieberman and Craft (46) isolated cytoplasmic particles from apples that produced a gas which was later identified as ethane (45).

Other Factors Affecting Ripening

A number of factors could be discussed in detail here, but many of them are closely related to maturity and have been covered under the section of this review dealing with maturity. Fertilizers have been given wide consideration in their effect on maturity and ripening. In general, increasing levels of nitrogen result in fruit with less red and yellow ground color that are softer at harvest and after storage and respire at a higher rate (13, 67, p.1). Work

in Australia (75) indicates that borax sprays hasten maturity and ripening. Hormone sprays for the control of preharvest drop frequently hasten ripening and shorten the storage life (18, 34, 48, 68).

Radiation in excess of 10,000 rads from a gamma source was found by Massey et al. (47) to cause an immediate softening and a transient stimulation of oxygen consumption. However, the irraidated fruit softened at a much lower rate in storage, which gave a net result of somewhat firmer fruit than normal. Smock and Sparrow (66) reported earlier that Greening and Cortland apples treated with 40,000 rads softened more at 74° F. than untreated fruit. A Russian report (57) states that apples treated with 400,000 rads showed a drop in monosaccharides and a rise in starch content. Reports from the Danish Atomic Energy Commission (50, 74) state that apples treated with 50,000 to 100,000 rads developed no storage rots at 12° C. (53.6° F.), but quality deteriorated. At 20,000 to 40,000 rads the apples were firmer with less rotting in storage, and respiration was significantly reduced.

Compositional Changes During Ripening and Storage

Esselen et al. (14) gave the average composition of the edible portion of fresh apples as 84.1 percent water, 0.3 percent protein, 0.4 percent fat, 0.29 percent ash, 14.9 percent total carbohydrates, and 0.47 percent acid. Strachan et al. (70) conducted a comprehensive study of the proximate composition of several varieties of apples grown in British Columbia. Kenworthy and Harris (36) obtained several varieties of apples from widely scattered areas of the U. S. for 3 years and analyzed them for 26 constituents. More significant differences were found for years than for any other variable. Neither of the above studies considered changes during ripening or storage. Some of the changes occurring in the various groups of constituents during ripening and storage are discussed in the following paragraphs.

Carbohydrates

Kertesz et al. (38) investigated firmness and cellulose content of 17 varieties of apples at commercial harvest and after 102 to 135 days of storage. Although cellulose is considered a factor in firmness, changes in the amount or quality of cellulose were not found to be involved in the softening that occurs during ripening and storage. However, Wiley and Stembridge (80) noted an increase in cellulose content during storage and with softening of the tissue.

Perhaps the greatest change in carbohydrates occurring during ripening involves the pectic constituents. Softening, one of the most noticeable characteristics associated with ripening, appears to be closely related to a decrease in insoluble pectins (protopectins) and an increase in soluble pectins. As apples pass their peak of eating acceptability and become mealy, the soluble pectins decrease again and the insoluble protopectins may increase (28). A very close direct relation between hardness and protopectin content has been observed (78). The degree of softness as measured by a penetrometer, such as the Magness-Taylor pressure tester, or with a mechanical thumb instrument (60) provides an index of ripeness that guides the producer and storage operator in timely marketing of apples for better quality. Storage temperatures profoundly affect the formation of soluble pectic constituents (37). All ripening reactions, including the pectin transformations, proceed at a much lower rate at

low temperatures. Although it has been difficult to establish the existence of the pectin splitting enzymes, pectin methylesterase and pectin polygalacturonase in apple tissue, there is evidence of pectin methylesterase activity which results in demethylation and increased viscosity of pectin solutions (33, 56). Sapozhnikova (58) reports lower activity of pectolytic enzymes in apples more suitable for storage.

The amount of starch in apples after harvest is relatively small and by the time the respiration peak is reached a large portion of the starch has disappeared (29); therefore changes in starch and activity of starch splitting enzymes would not be expected to be involved to any great extent in the ripening process. However, Wiley and Stembridge (80) found starch content to be closely related to texture in processed apple slices.

The sugars are important because of their relation to eating quality. The principal sugars in apples are fructose, glucose, and sucrose. The presence of xylose in small quantities has also been observed (1, 61). The sugar/acid ratio has been considered by many to be a measure of ripeness and eating acceptability. The increase in sugar content during ripening and storage was earlier presumed to come from the hydrolysis of starch, but the increase has been reported to be greater than can be accounted for by loss of starch (22, 25). The organic acids play a very important role in respiration and are probably much more closely connected with the sugar metabolism (28, 41, 42) than was earlier considered possible.

There is no recent evidence to indicate that other carbohydrate fractions, such as hemicilluloses, pentosans, etc., have any more than a very minor relation to the ripening process. Krotkov and Helson (41) have shown a slight but steady decrease in hemicellulose content in apples during storage.

Acids

Acidity or tartness has long been considered a quality factor in apples. Many measurements have been made to relate the total titratable acid to eating quality. Wright and Whiteman (83) found that acid content varied considerably between varieties and within varieties from year to year. They noted a progressive decrease in acidity during storage along with a slight increase in total sugars throughout most of the storage period.

It has been assumed that malic acid, because of its abundance in ripening apples, was the most important acid. With the evidence now available that the Krebs cycle is operative in apple tissue (20, 35, 43, 52, 72), this assumption cannot be accepted without question. Accumulations of malic acid may simply serve as reservoirs for feeding acids into a complicated cycle of transformations (28) where minute quantities of certain acids may serve an extremely important function in the metabolism of the harvested fruit.

A number of organic acids besides those involved in the Krebs cycle have been identified in apple fruit tissue. Some of the more recent ones include quinic (23), shikimic (27), and citramalic (5, 26).

Phenolic Compounds

The astringency characteristic in apples is usually considered to be caused by the phenolic compounds, more commonly called tannins in earlier years. In addition to their effects on flavor they are also responsible for the color

of the skin and the browning of the cut surface. They have not been shown to have much influence on the ripening of apples or to be markedly affected during ripening. Chlorogenic acid, which has been identified as one of the main phenolics in apples (24), decreases during ripening (29). The function of the phenolic compounds and their fate or role during ripening are largely unknown. Walker (79) found a steady decrease in concentration of chlorogenic and P-coumaryl-quinic acids during early growth and development of apple fruit. Both acids reached a near steady level at maturity.

Nitrogen Compounds

The primary change occurring in the nitrogen compounds during ripening has already been mentioned in the discussion on the climacteric. It is during this period that the balance between protein and nonprotein nitrogen is shifted toward a predominance in protein (25). There is little evidence of any significant changes in the total nitrogen content in apples after harvest (65).

Nutritional Value

Historically, the apple has been known as a fruit whose consumption reduces the need for a doctor. Besides having color, appetite, and variety appeal, there is considerable evidence that it also possesses definite nutritional and therapeutic properties (14). The average composition of the apple does not reveal any peculiar content that should make it especially beneficial. The balance of minerals, vitamins, acids, proteins, and carbohydrates with a relatively low total caloric value apparently is such that many people who eat apples experience a beneficial health effect.

Dedolph et al. (11) found that over 400 students who volunteered to eat apples every day during the first and second quarters of successive academic years at Michigan State University made significantly fewer calls at the University Health Service Clinic than would be expected on the basis of the entire student body. This was especially true for upper respiratory and tension-pressure phenomena disorders.

Slack and Martin (62) observed two groups of 80 to 90 children over a 2-year period in Liverpool, England. Instructions were given that one group should be served apples after each meal and after eating between meals. The other group served as a control. No instructions were given concerning oral hygiene. After 2 years the gum condition of the children in the apple group was significantly better than in the control group. The effect on reducing the incidence of dental caries was also encouraging. The authors considered the results of this pilot study justified a larger scale study for a longer period but pointed out that crisp high quality apples were needed to obtain the beneficial effects.

Apples are a relatively good source of ascorbic acid (vitamin C); however, varieties differ widely in their content. Grant (17) reports values for 23 varieties ranging from 0.9 mg. for McIntosh to 12 mg. per 100 g. of cortex tissue for Wagener. Kieser and Pollard (40) report a range of 6.9 to 22.5 mg. per 100 g. of fresh tissue for 17 varieties of English apples. Hundreds of varieties and seedlings have been analyzed and nearly all of the values will fall within the wide ranges just cited. Grant (17) also indicates that very little loss of ascorbic acid occurs during storage. Others (49, 55) have found

losses from 50 percent in 8 months of storage at 40° F. to as much as 50 percent loss in 1 month at 3° C. (37.4° F.). However, it appears that storage conditions can be maintained to keep ascorbic acid losses at a level where the nutritive value will not be seriously affected (69).

The apple also contains other vitamins but cannot be regarded as a rich source of carotene, thiamine, or any of the B vitamins.

The sugars are readily available carbohydrates and, as mentioned earlier, a ripened apple contains almost no starch. The pectins may be responsible for some of the health-giving properties. They appear to be a beneficial supplement to a diet deficient in vitamin A and have been recognized as having properties that aid in curing diarrhea and other disorders (14).

The minerals in apples do not differ much from those of many other fruits. The mineral cations associated with the organic acids leave a basic residue in the body when the acids are oxidized. Although quite acid in taste, apples do not reduce the alkali reserve of the blood (14).

A quotation from Esselen et al. (14) summarizes this section very well: "We have always eaten apples for their zest, attractiveness and flavor. Now with a recognized food value assigned to them we can appreciate apples for their nutritive as well as their aesthetic value."

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The movement of apples from the growing and storage areas to the consumer is an important part of the marketing of this commodity. Loss of quality during this period must be minimized or prevented by providing the proper environment and by careful handling at every step along the way. Since ripening, softening, and decay development is retarded by low temperatures it is necessary to maintain such temperatures during transit, especially for fruit that has been in storage a considerable time (5). 1/ Since low temperatures maintain firmness, this also minimizes the susceptibility of the fruit to bruising (19). However, constant attention to careful handling during loading and unloading is essential to prevent bruising.

Freshly harvested early-season fruit that moves directly to the market for immediate consumption may be shipped under more moderate temperature conditions. However, fruit shipped at harvest that is destined for storage should be cooled rapidly and shipped under refrigeration to hold ripening to a minimum according to Redit and Hamer (12). They further state: "Apples of any variety harvested near the end of the season are more mature than those harvested earlier, so further ripening in transit before consumption may not be necessary. It is especially important, therefore, that this late fruit be shipped at low temperatures." All apples shipped out of cold storage should be maintained at or near the storage temperature to maintain their quality, especially those shipped late in the season after long storage. Fruit shipped during the cold winter months should be protected from possible freezing damage by an adequate heater service. Overheating must be prevented by the use of thermostatically controlled heaters and proper air circulation in the vehicle.

In order to select the proper protective service at shipping point and to evaluate its performance upon arrival at destination, fruit temperatures should be checked accurately. Suitable thermometers and their proper use are described by Guilfoy and Johnson (7).

When apples have been stored in film-lined containers, Gerhardt (4) recommends that the sealed film be perforated or slit open at the shipping point to avoid possible injury to the fruit when exposed to room temperatures during wholesale and retail handling.

Methods of Transportation

Trucks

In areas where apples are produced and stored close to the market and where transit time is 24 hours or less, trucks are used almost exclusively. This applies particularly to the eastern and midwestern areas. Merchant (10) reports that as early as 1943 there was a steady trend to trucking Maine apples to market and today it is practically 100 percent. This same trend is indicated in a study of truck movement of apples in the Appalachian Belt by Snitzler (17).

For short distances requiring only an overnight trip, refrigeration is not usually required. However, in northern areas, heaters should be used in extremely cold weather to prevent freezing damage. Movements requiring several days such as transcontinental hauls from the Pacific Northwest to midwestern

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1/ Underscored numbers in parentheses refer to Literature Cited, p. 126.

or eastern markets should be properly refrigerated or heated in accordance with prevailing weather conditions. Thermostatically controlled mechanically refrigerated trucks and trailers with adequate insulation are preferred to ice-refrigerated units. Some mechanical systems are designed to heat as well as cool. Thermostatically controlled liquid fuel heaters are available for protecting against cold (11). Proper loading of trucks and trailers to prevent excessive bruising and container damage is described by Johnson and Breakiron (9).

Rail Shipments

The majority of long distance shipments are still made in rail refrigerator cars, especially from the west coast. Equipment available includes ice-refrigerated fan cars, thermostatically controlled fan cars with ice refrigeration, and mechanical cars capable of both refrigerating and heating. Mechanically equipped truck-rail (piggyback) trailers operated by the railroads are rapidly becoming available. They offer many of the advantages of the over-the-road trucks, such as door-to-door delivery and reduced handling.

The protective services available for rail shipments include refrigeration, ventilation, and heating (12). The use of car fans to obtain more uniform temperatures is very important under both refrigeration and heater service in providing more uniform temperatures throughout the load (6, 12, 13, 14, 15, 18). Fisher and Smith (3) state that ventilation service is justified only with apples that are intended for immediate use, because of the lack of temperature control under this service. Otherwise, cars should move with vents closed. Liquid fuel (LF) heaters with thermostatic control have been adopted as standard equipment by most of the railroads in the United States as a result of extensive tests conducted cooperatively by the U. S. Department of Agriculture and the Association of American Railroads (AAR) (13, 14). In thermostatically controlled fan cars (Ice Tempco) the desired temperature is set on the thermostat while the car is under refrigeration. When it is used with LF heaters, the heater thermostat is used for control. In mechanical cars, the railroad sets the thermostat to provide the desired transit temperature, whether under refrigeration or heat.

Containers and Loading [2/]

Many new containers are now available for apples; they are described elsewhere in this publication. One of the purposes of an adequate container is to protect the commodity from damage while in transit. Proper loading patterns are required to prevent container damage and also to provide adequate air circulation for proper temperature control.

Recommended methods of loading various containers in refrigerated trailers are illustrated by Johnson and Breakiron in Agriculture Handbook 105 (9). A comprehensive study of truck shipments of McIntosh apples from New England to Florida is reported by Shadburne (16). He found that the containers should be of uniform size to minimize container damage. To prevent damage from containers

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2/ See also section on Shipping Containers and Consumer Packages.

shifting backwards in the rear stacks, an effective load locking device is recommended. The necessary air circulation for proper refrigeration of the load was obtained by lengthwise channels, a space of 10 to 12 inches between the load and rear doors, sidewall stripping, and adequate floor grooves or racks. Ventilation holes or slots in the cartons would also improve fruit temperatures.

Loading patterns for rail refrigerator cars are prescribed in the various railroad freight container tariffs. In a good load, the containers must be placed to take advantage of their maximum strength and permit adequate stripping or use of spaces to maintain alignment and necessary air channels. Adequate bracing should be used to prevent load shifting in transit.

The benefits derived from bulk and pallet handling of apples in harvesting, packing, and storage may be extended to transportation as well. Breakiron (1) indicates some of the advantages and disadvantages of pallet containers for shipping.

Another method of unitized loading in which the containers are strapped on a disposable pallet has been reported by Carlsen and others (2). These units were placed in the vehicle by forklift truck with a minimum of hand labor. They moved well during transit, but some difficulty was experienced at unloading in removing the doorway pallets because of a load shift.

Further developments in equipment and methods of bulk handling may be expected that will contribute to lower transportation costs and reduce loss of quality in the movement of apples, particularly for processing and consumer packaging in the retail distribution areas.

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TERMINAL MARKET HANDLING

Wholesaling

Much research on the prevention of bruises on apples has been reported in another part of this bulletin. A few such studies particularly concern terminal markets. Herrick and co-workers (18) 1/ found that as fatigue of workers increased, care in handling produce decreased. They found that much fatigue can be minimized by the elimination of vertical lifting associated with loading and unloading produce. Handlers should be instructed to keep as many as possible of their movements on a horizontal plane. Effort has been wasted when the top box of apples on a two-wheel truck has been lifted from the floor of the car and when the bottom box on the truck was taken from the top layer in the car. Wasted efforts cause wasted apples. See also (26).

Other practices in terminal markets that cause bruising of apples are related to supervision. Often parts or whole loads fall from skids or pallets because workers have not been taught how to alternate the position of packages in successive layers so as to cross-tie them together (18). Boxes of apples that bulge on the sides or tops should be stacked on the flat side or on the end of the package. See also (14). No boxes should be stacked so high that the warehouse workers must walk on them to build the stacks (5). Whenever boxes are stacked this way, some apples invariably will be damaged (5, 18, 37).

Bogardus and Lutz (3) have cautioned that wholesale warehouses should provide adequate refrigeration at all times to maintain the quality of produce. Storage temperatures for most varieties of apples should be 30° to 32° F. (35, 40). Comin (8) and Bisno (2) reported that the deterioration of such apples approximately doubles for each 10° rise in storage temperature above 32°. However, some varieties require 38° to 40° F. (35, 40). Most varieties of apples freeze at about 28° to 29° (13, 38). Apples should be stored at 85 to 90 percent relative humidity (40). To maintain high humidity, the refrigeration should be so designed that not more than a 2-degree difference exists between the refrigerated coil surface and the storage air temperature (3).

When sealed film-lined boxes of apples are removed from cold storage, it is recommended that the liners be either perforated (28) or removed or slit open (12, 35, 39), if the apples are to remain more than a couple of days at room temperature. Otherwise, the apples may develop off-flavors.

McIntosh apples after removal from storage may change their flesh color from yellow to greenish-yellow and then back to yellow if kept at room temperature (34). Francis (10) and co-workers determined that the change back to yellow is mainly due to synthesis of carotene, but the change toward greenish-yellow may be due to the balance between carotene and chlorophyll. The amount of chlorophyll decreased slightly when the fruit was left at room temperature. It was concluded that the main color change was due to a change in carotene.

Air spaces between loads, as well as between the produce and storage walls, should be provided to avoid the occurrence of warm areas (3). In 1958,

1/ Underscored numbers in parentheses refer to Literature Cited, p. 131.

Fisher (9) found that fruit cools slightly better in cardboard containers, provided they are spaced. His experiments showed that boxes not spaced took 13 days to cool from 50° to 32° F. Those that were spaced took only 6 days. If coldroom doors in warehouses must be opened often or for prolonged periods, the use of air curtains is advisable (3).

Retailing

Storage and Display

What is done commercially often is the basis for research to learn whether a practice is good or bad, and whether it can be improved to maintain higher quality produce. See (4). In 1952, Hinkle (19, 20) noted that only 2.3 percent of 230 retailers refrigerated their apples on display. In 1953, Lewis (22) studied the condition and quality of northwestern apples after they were displayed several days refrigerated and not refrigerated. He reported that apples of good quality and condition may be displayed on nonrefrigerated racks for several days without a significant loss in flavor or an increase in ripeness. He concluded, however, that apples that are refrigerated will retain an attractive appearance and crisp texture longer than apples held at room temperatures. See also (24). In 1955, he reported that the temperature of apples displayed without refrigeration averaged about 73° F.; those on a false rack, convection-type, mechanically refrigerated case averaged 64°; and those on a regular refrigerated rack averaged 44° F. (23). In 1959, some 18 percent of the retail stores sampled in Los Angeles, Chicago, New York, and Washington were displaying apples under refrigeration. 2/

In 1946, Haut (16) found wide differences in apple behavior at 45° and 55°. Senn and Scott (30) further examined these differences in 1952. They found that firmness and succulometer readings were more closely related to organoleptic values than were respiration rates and dry weights. Richared Delicious apples maintained acceptable ratings for 18 days at 45° F., 9 days at 50°, and 6 days at 55° F. A study in 1960 (17) showed that apples displayed under simulated retail refrigeration (47° to 52° F.) lost less weight and showed less decay than similar apples displayed 4 or 7 days at room temperature (75° F.).

The recommended temperature range for display of apples is 32° to 45° F. If apples are not refrigerated during the daytime, it is recommended that they at least should be kept cool at night (25). Should apples become frosted they should be thawed out slowly (11, 13, 27).

Hinkle (19) found that 80 percent of 173 retail stores in Syracuse, N. Y., in 1952, gave no overnight care to apples on display, 11 percent covered the apples dry, 1.7 percent covered them wet, and 6.9 percent of the stores removed their apples to coolers. He found that spoilage rates were very low on dry displays regardless of overnight practices. In general, research has shown that without refrigeration all apples age rapidly, develop a mealy texture, and soon become worthless if not refrigerated or sold (24).

Lewis (22) found that sprinkling had no material effect on the quality and condition of northwestern Delicious apples on retail display. Norwood (25) recommended that no apples on display should be sprinkled.

2/ Unpublished report on file in Market Quality Research Division, Horticultural Crops Branch, Plant Industry Station, Beltsville, Md.

The best practice for all varieties during hot weather is to display only as many apples as can be sold in 2 or 3 days (11). Reserve supplies may beheld satisfactorily for short periods at 32° to 50° F., the lower temperature giving the best results (5, 24). Apples should be kept cool, dry, out of the sun, and provided with ventilation. Rotten apples should be removed from displays promptly (5, 31, 32). The principal factors of deterioration that may be retarded by refrigeration are softening of the flesh, internal breakdown, discoloration of bruises, and decay (24). Delicious apples soften more quickly than other varieties (11). Senn and Scott (30) noted that the borderline consumer acceptance of Richared Delicious apples was associated with a firmness rating of about 12 pounds.

In research designed to represent 42 million households in the United States, 79 percent of those using fresh fruits said they preferred apples to other fruits. Among criteria for selecting their apples, the absence of bruising was mentioned most frequently (7). To lessen handling of apples and to offer higher quality as a result of less bruising, many retailers display apples in the original shipping containers (20, 29, 37). 3/ Hinkle (19) found no significant losses in sales between apples displayed in wholesale containers and those displayed otherwise. Some stores build displays with the molded pulpwood trays lifted directly from shipping containers to the display counter. This method discourages unnecessary handling of the apples by the clerks and customers, lessens labor, and insures rotation of the stock (1). 3/

Toothman and Anderson (36) designed equipment for retailers to assemble displays within backrooms instead of in consumer areas. The system requires display sections to be put in trays of uniform size. These trays are moved to the buying area and quickly lifted onto modified display counters whenever the produce display needs either replacement or rotation. Among the several advantages of the system is reduced bruising due to less handling, provided the trays are adequately padded and free of sharp edges.

Oil wrappers are used to some extent on apples to control storage scald. This purpose was unknown to most retailers in one survey, 3/ but they invariably associated the presence of the wrappers with high quality apples. The retailers reported that customers handled wrapped apples less frequently and more carefully than unwrapped apples.

Apples sometimes absorb odors from adjacent produce. It is recommended that apples, either in storage or on display, are not placed near onions, cabbage, potatoes, or root vegetables (21, 25).

Shelf Life

The shelf life of apples roughly is inversely proportional to their respiration rates. The average respiration rate of apples at 70° F. is estimated to be about 3.2 times the rate at 40°; and at 40° the rate would be about 47 percent greater than at 32° (35). Bisno (2) reported that if the shelf life of apples at 70° F. were taken as unity, apples would last twice as long at 50°, four times as long at 40°, nine times as long at 32°, and twelve times as long at 30° F. However, as earlier pointed out in this section, a few varieties are not tolerant to prolonged storage below 40° F. See section of this bulletin on Precooling and Temperature Effects During Storage; also references (24, 35, 40).

3/ See also footnote 2, p. 129.

Hauck (15) found that only 28.2 percent of Rome Beauty apples held in bulk at 65° to 80° F. and 37 percent relative humidity were salable at the end of 18 days. At the end of 21 days, 83.3 percent of the apples held at 45° to 56° F. and 72 percent relative humidity were salable. Similar apples packaged in paperboard trays, sealed in cellophane, but not refrigerated, were only 55.8 percent salable at the end of 20 days. Refrigerated apples were 92.4 percent salable at the end of 31 days.

In 1960, the keeping quality of apples was found to be unaffected by the type of package when displayed in either cellophane sleeve-wrapped trays, cellophane overwrapped trays, open trays, or in polyethylene bags (17). See also (33).

Carlsen and Stokes (6) determined the length of time required for prepackaged apples to reach consumers. Less than 7 days elapsed time was reported by 3.5 percent of the respondents; 63.1 percent reported 8 to 17 days; 13.6 percent, 18 to 22 days; and 2.4 percent replied that over 37 days had elapsed between the date on cards inserted in the packages and the date the apples were purchased.

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BRUISE CONTROL 1/

The per-capita consumption of apples within the United States is about two-thirds of what it was 20 years ago (23, 78, 103). 2/ Since most people like apples, many of the failures to buy them must be the result of objections either to price or to condition of the apples offered, or to both of these factors. It seems significant, therefore, that bruising or mechanical injury was found to be the main cause of inferior McIntosh apples in 168 Massachusetts retail stores (85). Similarly, bruising was found to be present on 85 percent of the Delicious apples on sale in Chicago, Los Angeles, New York City, and Washington, D. C. 3/ Several other studies have shown that practically all apples on retail display are bruised (8, 15, 38, 40, 47, 78). There appears to be little doubt, on the basis of sales alone, that buyers are not satisfied with the condition of the apples offered for sale (46) and that the control of bruising is highly important. Research on this problem is here reported under the subsections: (a) General, (b) Farm and Orchard, (c) Packing and Storage, (d) Transportation, Warehousing and Hauling, (e) Retailing, and (f) Supervision.

1/ See also section on Shipping Containers and Consumer Packaging.
2/ Underscored numbers in parentheses refer to Literature Cited, p. 150.
3/ Unpublished reports on file in Market Quality Research Division, Horticultural Crops Branch, Plant Industry Station, Beltsville, Md.

General

Bruising is considered to be the most serious defect of apples (86), and the principal consumer complaint is that bruised apples are not worth the price often asked for them. 4/ The consumer often pays higher prices for apples than for eggs, yet the apples are 30 times more often damaged (38). It seems sure that bruising hurts the market for apples whenever the housewife must trim away any bruised or damaged tissue (46). Some retailers reported it is impossible to sell badly bruised apples at a price that will return a profit (38). In New York markets, Blanch (8) reported in 1946 that seriously bruised lots of apples were discounted as much as 28 cents per bushel over those least bruised. The discounts for intermediate bruising were in proportion. It was reported in 1948 that apples auctioned with severe bruising present were discounted 8 percent (108). Bruise credit allowances to retail outlets by chainstore systems were found to average 5 percent (33). McColloch and Hansen 4/ reported that 46 percent of the unsalable fruit discarded by retailers in Washington, D. C., and Baltimore, Md., was due to bruises. Costs on the New York market alone were estimated to be $3 million yearly for bruising discounts, and another $2 million was lost by culling of bruised apples (109). Losses to the industry as a whole due to bruising have been estimated to be over $10 million annually (23, 38, 46).

The interaction of price and volume of sales has often been considered a means of selling bruised apples. However, investigators have found that the effect of this interaction generally was insignificant (5, 11, 104, 106). Armentrout (5) found that at best customers will pay no more for apples that have one-fifth the number of the bruises of an adjacent lot of apples, and he reasoned that customers probably do not make relatively narrow quality distinctions. Others commented that customers are concerned not how many bruises are present on apples but rather whether the apples are bruise free (8). If apples cannot be purchased without bruises, it appears that sales will be made but in lesser volume. Woodward (120) found that when 1 to 3 slight bruises per apple increased to 3 to 5 moderate ones, sales dropped 26 percent. When bruising became 5 or more moderate-to-large bruises, sales dropped another 3 percent. In 1951, a New York experiment showed that retail sales of apples might be increased about 10 percent if apples with only one-fourth less bruising could be offered consumers (105).

Interest in reducing bruising of apples seems to have begun in earnest in the early fifties. In 1952, Brunk (12) observed well over 100,000 customers in large cities and in large stores during 3 months, and concluded that bruise-free apples increased sales 20 percent over sales of apples that were not bruise free. In Michigan retail stores, customers bought 28 percent more of carefully handled apples than of apples that were badly bruised; and it was found that the bruising could have been reduced at little or no added cost (1). In Dallas, 65 percent more customers in chainstores bought from displays that had the fewest bruises and increased their purchases by 69 percent. Twice as many apples were sold from the better condition display as from the poorer ones. It was reasoned that an apple crop two-thirds larger than normal could be moved if bruising could be eliminated (35). In another survey (120) sales of bruise-free apples were 79.6 percent greater than sales of apples of the same quality

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4/ See footnote 3, p. 134.

but not bruise-free. Sales were 23 percent greater from bruise-free fruits even at one-half cent more per pound. The Washington State Apple Commission reported that a decrease of 22 percent in the severe bruising of Delicious apples on display between 1946 and 1955 had meant a gain of $2 million annually to the gorwers of Washington State alone (35).

Various workers have sought to proportion the responsibility for bruise occurrence among the agencies between the grower and the consumer. It appears from the surveys available that the orchard handling of apples may be responsible for 30 to 72 percent of the total bruising, from 3 to 34 percent may occur during grading, packaging, and other handling, and the total from all sources may equal 64 to 97 percent by the time the apples reach the consumer (8, 15, 20, 36, 38, 40, 47, 57, 78, 79, 88, 105, 109, 119). Comin (23)found that bruising occurs in every step of apple handling in the following order of importance: Dumping the apples into field crates, dumping on receiver belts, grading, lidding, picking, packing, and orchard handling. Perkins (78) and Hauck (47) separately reported that 70 percent of the severe bruising occurs after the apples leave the farm. Friedman (33) estimated that transit losses, including bruising, approximated $14 per carload for 21,377 cars, and that losses during marketing were 21 percent at the wholesale or storage level. It is estimated the apples receive an additional 10 to 25 percent bruising by the time the customers buy them (104, 120).

Apples are bruised when cellular structures beneath the skin are broken sufficiently to expose the cell contents to intercellular air and oxidation (70). Bruises can be divided into three types: (a) those caused by dropping, (b) those caused by contact with a rough surface, and (c) those caused by pressure (46). Larger apples are more susceptible to mechanical injury than smaller ones (44, 78, 119), but all of them bruise and develop skin breaks on even short drops of an inch or two (28, 38). Green (43) cautions that to prevent bruising no free drops, however small, should be permitted. When apples are dropped on one another, several bruises usually result (114); the damage is greater when apples fall on a flat surface (38). According to Gaston and Levin (38), moderately serious bruises occur on Wealthy apples when the pressure on them equals about 7 1/2 pounds, on McIntosh at 8 1/2 pounds, on Northern Spy at 12 pounds, and on Jonathan apples at 18 pounds.

In 1962, Mohsenin (70) and co-workers (71) reported on equipment they used to study precisely the energy required to bruise apples. Their stress curves showed that a low force of long duration could produce as much bruise as a high force of short duration. This element of time in bruising had not previously been recognized. Their data also showed that their test apples were most susceptible to bruising about 1 to 2 weeks after harvest.

Dedolph and Austin (26) determined the severity of bruises did not vary with the location of the bruise on Cortland and Northern Spy apples, but there was a difference in bruise severity with location on Jonathan and McIntosh apples. Other workers found that 99 percent of all bruises and 93 percent of all stem punctures occurred on the cheeks of apples (75, 80). These stem punctures, often classed as bruises, were found on 5.6 percent of test apples shipped in Maine in 1949 (119). Ceponis and co-workers (20) observed stem punctures in 6 to 30 percent of the McIntosh apples sampled from retail displays in New York City. They found bruises one inch or less in size on 21 to 100 percent of the same lots.

Various workers (31, 37, 40, 85, 88, 119) have used diameter of bruised areas as the criterion of bruise damage to apples. Burt (14) suggested that

depth of the bruise also should be considered. Dedolph and Austin (26) followed this suggestion to advantage in their study of impact bruises.

Many small bruises that do not seriously affect the appearance of apples may puncture the skin and permit the invasion of rot-producing fungi (91, 121). Hardenburg (46) pointed out that bad bruises are potential avenues of blue mold rot infection to almost the same extent as skin punctures. Wright and Smith (121, 122) showed that, depending on apple maturities, blue mold infections at bruised areas averaged from 55 to 70 percent and a tenth or less of this at nonbruised areas. English, Ryall, and Smith (27) noticed many lenticel infections in the bruised areas of apples. Southwick and Hurd (95) reported that a single severe bruise on an apple may increase moisture loss by more than 400 percent. Phillips (82) believed that impact bruising was responsible for the onset of senile breakdown after 3 to 6 weeks. Although most harvested produce is well covered with micro-organisms, the skin of apples offers good protection from them provided it is unbroken (46). Thus, bruise control is a most important step in decay or rot control (28, 36). See also section on Market Diseases.

While there is some difference in bruise resistance of different varieties of apples, this difference probably is less than growers and handlers imagine (38). Perkins (78) found that more than one-third of the McIntosh apples on retail display were badly bruised. Van Waes (104) found that even when this variety was carefully handled, bruising still amounted to about 17 percent by the time the apples left the farm, 33 percent by the time the apples were through storage operations, 49 percent on delivery to retailers, and 59 percent before they reached the customer. Similar apples not carefully handled were 85 percent bruised by the time they reached the storage. A study in 1949 showed that bruising was present on about 20 percent of Gravenstein apples before they reached the wholesaler (15). Delicious apples on display in Los Angeles during the springs of 1953 to 1956 showed two or more bruises the size of quarters on 18 to 32 percent of the fruits (36). In 1948, McColloch and Hansen [5/] found no consistent difference in bruising losses between eastern and northwestern apples on the Washington, D. C., and Baltimore, Md., markets. Studies are in progress in Japan on the possible culture of apples that may resist bruising (87).

Lott (61) studied bruise damage from hail on Golden Delicious, Starking, Grimes Golden, and Jonared. He found that no rots developed on slightly injured fruit when it was stored at 31° F. and 90 to 95 percent relative humidity for 60 days. Severe rot occurred, however, when the hail damage was very severe. Rot was most serious in Golden Delicious and in Grimes Golden.

Farm and Orchard

The bruising that apples receive on the farm or in the orchard varies with apple size and maturity, with equipment and handling techniques, and with the supervision of personnel. In nearly all cases larger, softer, and more mature apples bruise more easily (44, 78, 119). Burt (14) noted that McIntosh apples of only 9 pounds firmness (as measured with a Magness-Taylor pressure tester) were 21.6 percent bruised during experimental packing. Apples of 12 pounds firmness bruised 4.5 percent. Fruit that tested 17 pounds bruised 1.4

5/ See footnote 3, p. 134.

percent. Wright and Smith (122) noted that bruised late-harvested Delicious apples may be three times as prone to decay as early-harvested apples.

Studies in Michigan in 1951 compared the differences in care in handling 2 1/2-inch McIntosh apples during farm operations. Care in handling reduced bruising sixteenfold in picking the apples, twelvefold in dumping them into field crates, fourfold in dumping them onto the receiving belt, and fivefold in packaging them for market (38, 114). Woodward (119) found similar results. Smith and Wright (91) estimated that picking caused about 10 percent of the total bruising of apples; Van Waes (104) thought the amount to be about 25 percent.

Considerable difference in picking skill exists among workers (108). In a study by Smith and Wright (91) one orchard averaged 2 percent bruising, and three other orchards averaged 12 to 14 percent. The fastest picker was not always the best one. One picker harvested seven times as much fruit as another picker, but he also bruised the apples seven times as much. In another study, apples of the poorest picker showed 497 bruises per 100 apples; the best picker had only 17 (91). The best orchard averaged 37 bruises per 100 apples, and the poorest averaged 398. Care in handling can reduce bruising to at least one-third the usual amount (105). Gaston and Levin (38) found that careful picking reduced bruises from 81 to 17 percent.

A study in 1948 at Wenatchee, Wash., showed that if the extra apples with severe bruises caused by poor pickers were sorted out as culls, it cost the average grower $78 an acre to use poor pickers (108). Unless the apples with severe bruises were sorted out as culls, a shorter storage life and more decay could be expected. When the retailer or consumer has to throw bruised apples away, the poor pickers cost $191 per acre because freight and packing costs have been added. If the difference between severe bruising among the orchards studied in this survey was due to supervision, the poor supervision cost an average of $87 per acre. One less severely bruised apple per box will more than pay for a bonus to the picker and the cost of a checker (108).

To reduce bruising of apples during picking, the Washington State Apple Commission produced a movie for instructing pickers (113). To test the probable value of the film, some inexperienced pickers were divided into two groups. Only one group was shown the film on "Apple Picking Pointers." The group that saw the film picked apples with 59 percent less bruising than the group who did not see the film. A survey among growers indicated that pickers who use the best techniques also pick 50 percent more fruit (112).

Picking two apples with one hand may result in a bruise where the apples touch and where pressure is applied by the fingers (108). Pickers, sorters, and packers should wear gloves or trim their fingernails closely to prevent fingernail punctures. Women more often wear gloves than men do. This in part may account for the 50 percent less bruises and punctures on apples picked by women than on those picked by men. However, men pick from ladders to a greater extent (119), and these always cause some bruising of fruits. Other picking pointers include the picking bags should not be filled too full or allowed to bump against the ladder, the boxes, or any hard object.

Bruising frequently results from carelessness in transferring apples to the picking bag. Gaston and Levin (38) reported that it is not uncommon for pickers to drop almost all of the fruit from, or above, the top edge of the picking container. The lower layers in the container were most bruised; the top layers were least bruised. To reduce bruising in transferring fruit to field boxes, it is recommended that the bag be lowered into the box, then drawn gently upward and away (28).

Picking buckets rather than picking bags often are recommended to reduce bruising to a minimum (28, 93, 117). When 20-quart metal pails were used for picking apples, bruising and stem punctures amounted to about 10 percent; when canvas bags were used, the bruises and stem punctures amounted to nearly 78 percent (95). Southwick and Hurd further suggested that a container with rigid sides protects the apples when the container comes in contact with ladder rungs and tree branches. They cautioned, however, that to the extent the canvas bottom protrudes below the metal sides of the pail, additional protection from bruising is lost. McMechan (65) reduced bruising through use of a padded aluminum bucket. Among four types of picking containers, Hamer (45) found least bruising in metal buckets with flexible bottoms. Bruising was further reduced from 9.3 to 7 percent with buckets of the same design but made of fiberglass. In Pennsylvania, the type of picking container was less important than the way the picker used it (117).

The Washington State Apple Commission developed an apple sampler and scoring system to improve picking care (13, 112, 113). The sampler is a canvas cover with a small bag attached. The cover fits over the top of a field box of apples so that the box can be tilted on one end. Twenty apples are counted from the box into the sample bag, some from the bottom of the box and some from the top to give a representative sample of the picker's work. The apples in the sample bag are examined one at a time as they are replaced in the box. A scoring card allows tabulation of bruises, punctures, stem pulls, and off-color. No calculations in the field are necessary. The sampler reduces the work of inspection of a box of apples about two-thirds. For one grower, the use of the apple sampler and tally system reduced bruises as much as 45 percent in one-half day. The system increased the quality scores of some picking crews about 7 percent in 3 days. Burrell (13) has used an "Honor Roll" bonus system to secure bruise-free picking. He used the Washington sampler and one inspector per 20 pickers.

Many associations instruct their crew foremen to see that picking boxes and baskets are free of projecting nails. They also supply them with whiskbrooms to remove all sand, twigs, and splinters that might cause bruising (28). Little difference in bruising or stem punctures was found whether apples were dumped into padded or unpadded field boxes, but padding on the bottom of the field boxes reduced bruising from 52 to 38 percent when the apples were hauled from the orchard (119). Green (43) reported that foam plastic from bonded waste protected apples from bruising better than softer materials that deformed too readily. Field boxes should be filled less than level full to prevent bruising when the boxes are stacked (28).

While the use of baskets in the orchard is rapidly becoming obsolete, they still are used in some areas. The chief difficulty in their use is that when stacked they cause more bruises on the fruit than boxes do, because of their less rigid construction. 6/ The more desirable baskets are those with a solid or built-up bottom.

Krijgsman and DeRuiter (54) found that apples were less bruised when picked directly into a box raised on a stand than when they were picked into a pail. Clarke (21) studied picking directly into the final shipping container. This method requires careful selective picking and close supervision, but less bruising and handling are the rewards.

6/ U. S. Dept. Agr. Handling and Storage of Apples in Pallet Boxes. (Film.) U. S. Dept. Agr. Motion Picture Service, Washington, D. C.

Mechanical harvesting of apples has been studied in New York (56) and in Japan (87). LaBelle (56) noted the amount of bruising was similar to that on fruit picked by hand.

Work in the United States in 1949, New Zealand in 1952, Australia in 1953, and Canada and South Africa in 1959, indicated that subsequent bruising of picked apples may be lessened by using large crates or bins instead of individual field boxes. A few workers found the use of such bins of slight or no value in reducing bruises (55, 64, 73). Most reports, however, indicate that such handling does substantially reduce bruising of apples (3, 32, 41, 49, 50, 66, 78, 81, 84, 88, 91, 93, 97). Lötter (62) calculated that the larger the mass of the fruit in the container, the smaller the proportion of fruits in the loose top layer that are jostled and bruised in handling and transportation. Bruising is reduced because there is two-thirds less wood surface in contact with the fruit in a bulk box than in field crates bolding the same volume (49). Workers in Michigan found 50 percent less bruising of McIntosh apples when they were handled in bulk containers rather than in field lugs (41).

Smith and co-workers (93) noted that hauling bruises were only 7.7 percent when apples were handled in pallet boxes but 40.7 percent when loads consisted of individual field boxes. When apples were stored in individual field boxes bruising amounted to 52 percent; when they were stored in pallets (even when carelessly handled) bruising amounted to 32 percent. Another study showed a reduction of 7 percent. The results in this study varied with the variety of apple tested. Golden Delicious apples showed about 5 percent less bruising, Winesaps about 1 percent less, but Delicious apples showed 18 percent less bruising than similar apples harvested in standard boxes. Corrugated board was a definite help in preventing bruising against the sides of the boxes. It also helped when the pallets had diagonal corner posts (50). An available movie film fully illustrates the suggested practices. 7/

Hauling apples in bulk containers as much as 38 inches deep for a distance of 15 miles caused much less bruising than hauling apples in lugs, but it has been suggested that bruising can be minimized by using containers no deeper than 21 to 26 inches (3, 64, 97). In transporting apples from the orchard to the packinghouse, Southwick and Hurd (95) observed that slatted crates often result in much more bruising than crates with close-fitting boards.

That excessive bruising of apples occurs between most orchards and packinghouses is the consensus of many research workers. It is possible to eliminate practically all such injuries (85).

Packing and Storage

The delivery of bruise-free apples to customers depends on all personnel, techniques, supervision, equipment, maintenance, packing and packaging materials, fruit maturity, and even the weather. Phillips (82) found that late-harvested apples were more susceptible to impact bruising than apples that were harvested early. Delicious apples carefully packed during December and January averaged 17.6 percent severe bruising, whereas those carefully packed during February and March averaged 36.6 percent severe bruising (114). Extremely favorable conditions for decay are provided when wet apples are bruised. Extra care is

7/ See footnote 6, p. 139.

thus advised when apples are picked after a rain, are handled immediately after removal from cold storage to room temperatures, or are handled after the washing and packing operations (122). Some authors (68, 78, 79, 104, 119) estimate from 29 to 50 percent bruising takes place by the time raw-stock storage begins. Van Waes (104) thought pre-storage bruising of apples probably could be decreased to about 17 percent.

Bruising in storage has been estimated to be about 34 percent (104, 119), with a reduction possible to about 16 percent. Shock recorders placed in boxes of apples have shown that when boxes of apples are handled individually, some apples nearly always receive serious impacts (77, 93). Pallets and forklift trucks thus are being adopted in many growing areas for the hauling and handling of apples to reduce bruising, and to save time in receiving, stacking, and handling at the packinghouse (28). As previously discussed, the use of similar equipment in the orchards was found to reduce bruising there also (93).

Dumping apples onto the receiving belt has been considered to cause up to 96 percent of the packinghouse bruising, and it is believed this could be reduced between 68 and 80 percent (38, 114). Woodward (119) showed that care in dumping apples was more important than the type of container used for shipping the apples.

Bruises caused by leaf eliminators have amounted to 82 percent for traverse roller-elevator methods, and 42 percent for level shuffle-board progressors (93). Tests by Burt (14) showed that McIntosh apples of 15-pound firmness run through a leaf eliminator bruised to the extent of only 1 percent.

Smith and Wright (91) reported that different types of cleaning equipment was responsible for 45 times as much bruising in one packing plant as in another. In one instance, it was 15 times as great in one as in another, although the same type of equipment was used in each. They concluded this indicated sizable differences either in machine maintenance or operation, since the same quality of fruits was used in each of these plants. In 1949, they reported that apple bruising was 100 percent with a late-type dual-flood progressor, but was only 11 percent when the apples were dry wiped with canvas covered rolls (93). They found 89 percent bruising by towel driers but only 37 percent when the apples were air dried. Short rag-wipers inflicted far less bruising than long washers.

Also in 1949, Smith, Adams, and Wright (93) observed that bruising could be lessened by dumping apples into a water tank at the head of the receiving belt. By this method bruising was reduced from 121 to 49 bruises per 100 fruits. A hand operated mechanical aid for dumping fruit was developed by Gaston and Levin in 1951 that allowed even unskilled operators to eliminate from 60 to 70 percent of the bruising at the receiving belt (38, 60). In 1960, Pflug and Dewey (81) noted that water submergence of bins during unloading caused only a fraction of the bruising that occurred in a tilting bulk-box dumper. When the bins were vertically submerged, the fruits acted as a unit and 80 percent of them remained submerged. Only the top 6 inches of apples arose above the water surface and then spread out to a single layer.

Hunter, Kafer, and Meyer (53) compared bruising caused by a float-roll sorting table with that caused by a reverse-roll sorting table. They concluded that there was no difference in bruising on the two types of tables. The sorting operation is believed not to cause much increase in bruise damage (36).

Washing and grading operations have been reported to be responsible for 37 to 97 percent of all packinghouse bruises, second only to packing operations, with the potential reductions estimated between 4 and 55 percent (38, 91, 104). Roberts found that grading machines operated with care did not cause excessive

bruising (85). However, a faulty washer or grader may cost the grower about $120 per acre besides damaging the reputation of the firm or apple area (108). See also (37).

The effect of time and type of bruising is of significance in deciding whether to grade apples entering storage or after removal. Moving apples to cold storage without grading increased bruising 25 percent, but grading them before storage increased bruising 84 percent (117). Phillips (82) concluded that if apples graded out of storage were marketed immediately they could be handled with lower losses than if they were graded at harvest.

Skin-punctured apples generally are regarded as culls (28). Such apples amounted to 0 to 2 percent in one study of the various methods of grading and sizing and their effect on bruising incidence (93). Hand sizing and grading produced the most skin punctures, but there was little or no difference among other methods. The story was different for other bruises occurring during grading and sizing. Bruises were 43 percent for hand sizing and grading and were 91 to 95 percent with a machine equipped with spiral rolls, singulators, and weight-type sizer. With the latter method, the bruises averaged 296 per 100 fruits in one packinghouse.

Markwardt (67) in 1951 studied the bruising effects of various surfaces, sizing devices, and grading equipment. The oscillating cup and revolving wheel types of sizing devices showed the least amount of bruising. Chain and weight types showed the most. His recommendations included: (a) The use of wooden-roller sorters covered with one-fourth inch of firm sponge rubber; (b) use of a return-flow belt traveling at about 30 feet per minute; (c) a revolving-wheel type of sizing unit between sorter and return-flow belt; (d) no drops in elevation that allow apples to strike one another with sufficient force to cause bruising; and (e) belts should be kept under tension and not backed by a hard surface. Green (43) suggested that handling equipment should be so designed that no free drops, however small, should be permitted. He reported that reconstituted foam-plastic waste protected apples from bruising better than softer more readily deformed materials. Merchant (68) reported that bruising was greatest in packing plants using manual dumpers, chain eliminators, wooden sorting rolls, chain sizers and two-way belt accumulators. McIntosh, the second most important apple variety in the United States (102), is one of the most tender and easily bruised apples. Any packing line equipment that meets the requirements for McIntosh thus will be suitable for other varieties as well (14).

Occasionally it is questioned whether certain size apples bruise more easily than others. Apple sizes 88 and 113, for instance, are often reported difficult to pack to prevent bruising (114). Phillips (82) found bruising was influenced to some extent by size of the apple. Other studies have shown that one size of apple may be as carefully packed as any other, but larger sizes do bruise more easily than smaller ones. In one study (114) size 64 apples were bruised three times as much as size 125. In another study (36) bruising of apples ranged from 43 percent for size 64 to 8.2 percent for size 150. This susceptibility to bruising particularly emphasizes the need to tray-pack large size apples especially.

Packing Operations

Various research reports show that packing operations may be responsible for from 25 to 76 percent of the bruising of apples, with the prospect of

reducing this from 16 to 48 percent (38, 104, 114). It is certain that rough handling is a big factor (28). In 1949, a survey of packing operations in Washington State showed that relatively more bruised apples were found in the end of the box toward the packer and along the right-hand side of the box. Packers who caused least bruising kept the stem-end of the apples toward the end of the box, and had fewer oversize apples in the ends. Calyx ends of apples placed next to the box bruised most and slightly misplaced apples were more damaged than completely misplaced ones (110). Some packers caused twice as much bruising as better packers in the same house. Listed as poor practices of packing were: the use of force in packing, overfilling boxes, blossom ends of Delicious apples placed against the ends of the boxes, and failure to place large fruits in the middle of the boxes and the small fruits in the ends (36, 110).

Under simulated handling tests in Washington in 1951-52, it was found that a 3:2 pack produced 18.2 percent less bruising of apples than a 2:2 pack. These apples were standard packed with sulfite liners and chipboard tops and bottoms. While this type was the best for a standard pack, there still were over 52 severe bruises per 100 apples (114).

Trays and Tier Pads

Molded pulp trays did not appear until 1942, but by 1964 over 100 million such trays were used annually to prevent bruises to apples (63). They have largely replaced tier pads. The trays are molded to hold apples in definite relative position in accord with the number of apples to be packed in the box or carton. A standard pack carton can deliver apples in as good condition as the tray pack, and perhaps it is less costly than the tray pack (115). However, under commercial packing conditions, the tray pack delivers apples more bruise-free than the standard carton pack because fewer bruises are caused during the packing operations. Woodward (120) found 84 percent bruising in jumble packs and 68 percent in trays packs.

Smith and Wright (92) found that corrugated liners and indented tier pads, plus careful handling, could make the standard pack equal to the tray pack. It was thought that tier-pad packs might have some practical advantages over tray packs in piece-work systems, inasmuch as packers usually have too little time to see the tray pockets into which apples are to be put. Studies in Washington State (115), reported in 1953, showed that tier pads caused less bruising than when the pads were not used, and the amount of apples remaining sound was 10.4 percent greater. They found that the pads tended to hold the apples in place and to prevent settling, an occurrence that gives the impression of a slack fill. The omission of top or bottom pads in boxes often causes severe bruising of apples (83, 86).

Under simulated transit conditions, the Washington State Apple Commission (36) found that the tray pack and the heavy-tier padded packs were more than twice as effective as sulphite paper lined boxes in preventing bruises. Smith and co-workers (93) earlier found similar results occurred under actual transportation from Washington State to eastern markets. Tomcsanyi (100) reported in 1959 that of 15 methods of packing Jonathan apples, those packed in plastic-coated trays, 2 layers per container, showed least bruising after being transported 1,200 kilometers. In a similarly severe transportation test in Sweden in 1960, fiber sheets between fruit layers were reported to give the best protection of all the forms of padding tested (72).

Instead of molded pulpwood trays, polyurethane-foam pads were used by some packers in 1960. Fountain (30) compared bruising of apples when place-packed on 1/8-inch polyurethane pads with that of apples packed in trays and in individual cells. The bruising of Delicious and Winesap apples amounted to 8 to 10 percent in trays and 21 to 25 percent when place-packed. Golden Delicious bruised 18 percent when place-packed and 3 percent when packed in individual cells. Inspection of many cars of apples shipped in polyurethane packs indicated that 3/16-inch pads were inadequate to prevent bruising. It was the general conclusion of the inspectors that these pads do not protect Golden Delicious as well as cell packs, and pads do not protect Delicious and Winesaps as well as trays. Polyurethane pads thicker than three-sixteenths inch were not evaluated (98). In 1962, Fountain (31) tested various cushioning materials between layers of apples packaged in shrinkable films. He found none performed better than double-face corrugated board.

It was reported in 1953 that as many as five sizes of apples can be grouped in one standard box with no increase in bruising, provided proper packing technique is used. Small apples should be placed in ends of the boxes and the larger apples in the middle. Small and large apples scattered throughout a package increased bruising (34). This kind of pack requires close supervision; but, both experimentally and commercially, group-size packs have been produced with no more--and in some cases less--bruising than the regular standard pack (36). Further, it has been stated that these group-size packs permit not only the use of simpler sizers and easier segregation in the warehouse, but also they make possible easier mechanical packing of apples (34).

Float-packers have been used in the United States for some time to reduce bruising of apples and lessen packing costs. Essentially, these packers consist of sliding drawers with false bottoms. The apples are put into molded trays, and the trays are placed in position in fiber cases simply by pushing the drawer in, pulling it out, and then releasing the false bottom to allow the tray to settle into the case by gravity. This method also was introduced recently into Australia (2).

In 1955, Carlsen and Herrick (17) described an automatic box filler for loose-filling wood or fiberboard containers. They wrote: "It uniformly fills three to four boxes of apples a minute, or up to 1,600 boxes a day, when heavy supplies of fruit are available to the packing line. It provides more gentle handling of the apples, with less danger of bruising than most manual methods of box filling."

Burt (14) used an automatic box filler which reduced bruising of apples of 9.5 firmness to 6.4 percent from a former average of 21.6 percent. There was little or no significant difference in bruising of fruit that tested 16 or 17 pounds firmness.

Containers

Once it was customary for shippers to pack apples in wooden boxes in such a manner that a crown or bulge occurred when the lid was applied. It was assumed that a tight pack reduced damage to the enclosed apples and that buyers demanded the practice. In 1948, a Los Angeles survey (109) showed that 60 percent of the jobbers and retailers preferred a middle weight to a heavy pack, in order to obtain less bulging. The consensus was that the bulge pack produced not less bruising but more. The bulge pack often badly bruises every apple in contact with the lid, flattens those that touch the sides and bottom of the package, and many of those in the middle are deeply dented (46). The causes of

bruising listed in order of importance were: size of bulge, poor sizing, placement, and alignment of the apples in the containers. The Washington State Apple Commission recommended that if a wooden box is used for a standard pack, the packs would be better with no bulge and with the boxes stacked upright rather than on end. To accomplish this change, the usual wooden box should be deeper and the labels would need to be a different dimension (116).

A survey in Chicago in 1948 showed that a tray-pack in wooden boxes produced the least damage from bruising (109). Further research in 1953 in Washington State (115) showed that apples in fiber cartons reached retailers with far less damage than the average standard pack in wooden boxes. The carton resulted in practically no severe bruising, compared with 9 to 12 severely bruised apples per 100 when packed in wooden boxes. The number of apples that remained sound was almost twice as great in the fiber carton. They estimated that the carton saved about $80 per carload, or approximately $3 million per year, for the Washington State growers.

In another set of trials in 1953, a wooden box fitted with corrugated liners and made three-fourths-inch deeper, but with the same dimensions as the fiber carton, carried apples equally as well as the fiber carton (116). Trials made with six sizes of bruise-free apples showed 24.9 percent bruising in flat-top ply-veneer boxes and 32.7 percent in the standard wooden box.

The fiberboard carton, when jumble packed, was the most popular apple container received in Cleveland in 1953. Scott and Leed (89) reported that 40 to 45 percent of the operators of both independent and chainstores expressed a preference for this carton because apples received in it were less bruised than apples that had been shipped in other containers. Bushel baskets were next most popular, and consumer packs were third. Fiberboard cartons have been gaining in popularity also in Russia (100) and in Sweden (72), due to less bruising than in wooden boxes. In 1963, O'Loughlin and Chapman (74) found that severe bruising of apples packed in fiberboard cartons averaged only 0.25 percent compared with 4.25 percent in wooden boxes.

Egg-crate-type cells for individual apples are said to afford the maximum protection against bruising and skin punctures (3, 30, 75, 85). Golden Delicious, plus thin-skin and easily-bruised apples, generally are packed in such cells to limit bruising (63). Different sizes of apples, however, require different sizes of shipping containers (99). This makes it difficult to stack the containers safely in cars, trucks, or warehouses (28). O'Loughlin and Chapman (74) found no significant differences in bruising of apples in cell-pack and tray-pack cartons.

One firm in Australia has used 1/2-ton bulk containers for exporting apples to large chainstores. Among 250 tons so shipped in 1958, the incidence or bruising was reported to be only 3/4 of 1 percent (41).

Consumer Packages

The placing of apples in consumer packages once was done only by retailers or within packaging plants located at or near terminal markets. This work now is being done to some extent also at shipping points. This may have increased the bruising of apples in some instances. Suggested remedies include that prepackaging equipment be more skillfully designed (18) and that all packaging operations be performed with increased care (16).

Shadburne (90) observed in 1959 that bruising of apples was four times as great in bagged apples as when each apple was packed in an individual cell.

Similar findings have been reported by others (19, 28, 75, 85). Studies in Maine (75, 76, 80) showed that 9 to 19 percent of the apples jumble-filled into bags of 3- and 4-pound capacity are bruised by the time they reach the retailer. Bruising has been found to be nearly 30 percent greater in 4-pound hags than in 3-pound bags (80). Carlsen and Stokes (18) noted that bruising was greater in tighter fitting bags than in those which would permit the apples to shift a little when the bags were handled or transported.

Increased bruising evidently occurs when bags of apples are placed on end in the master shipping containers (18, 72). Perkins observed during a 3-year study that bagged apples placed vertically in a single tier may have up to three times as many severe bruises as when the bags are laid horizontally in two tiers (75, 76, 77). Moderate bruising in bottom layers of master containers may amount to five times that found in top layers (72, 78, 86).

Contour packing of apples shows some promise as a means of reducing the bruising of apples (4, 19, 31). Ceponis and Kaufman (19) reported that tray packs of McIntosh apples in heat-shrinkable films were second only to individual cell packs in reducing bruise incidence. They objected, however, to the weakness of the tray-separating partitions used in packing the trays. Fountain (31) found it necessary to place Golden Delicious, Delicious, and Winesap apples packaged in shrinkable films into cell-type master containers, one consumer package per cell, to protect them from bruise damage during transit.

Merchant and co-workers (69) found that packaged apples shipped in 275-pound-test master containers had 2.8 percent less bruising than apples shipped in 200-pound-test containers. See also (75, 78, 86).

Lidding Operations

The Washington State Apple Commission (36) stated that packing and lidding of wooden boxes caused more bruise damage than any other operations in the packing room. Smith and Wright (91) noted that packing-lidding operations accounted for 33 percent of the bruising of apples in four packinghouses. Some lidding operations contribute as much as 86 percent bruising (mostly due to overfilling), which can be reduced to at least 55 percent (38). O'Loughlin and Chapman (74) found that Sturmer apples were less bruised by automatic lidding than by lidding with a foot press. Van Waes (104) found very little bruising of apples during lidding operations done by hand; but when done by machine, the bruising was increased. Under controlled commercial conditions bruising from packing and lidding of standard-pack apples was 22 percent greater for small apples and 44 percent greater for large ones than bruising in tray-pack apples.

Stacking Operations

Better shipping-point warehousing methods can reduce bruising of apples (78). The use of pallets and forklifts has eliminated much bruising formerly caused by warehouse handling (50). 8/ The observations of Herrick and co-workers (51) on the stacking operations at terminal markets are equally important and applicable at shipping-point warehouses. See page 128. Sometimes attempts are made to force containers into places too small. Examination of such containers in all instances showed that the apples had been seriously bruised (38).

8/ See footnote 6, p. 139.

These bad practices, the results, and the remedies, apply also to loading cars and trucks. Shadburne (90) noted that most truck-transit damage occurred to apples in containers located at the rear of the trailers.

Transportation, Warehousing, and Hauling

When wooden boxes of standard-pack apples are loaded on their sides in cars or trucks, it is not uncommon to find all apples in contact with the sides of the boxes to be flattened in the bottom layers of the shipments (28, 86). Bruises produced by jolting and vibration of the standard-pack box against the car floor can be largely prevented by use of cushion liners and by careful handling of the boxes (83, 86). Smith and co-workers (94) found that the use in boxes of individual fruit wrappers, tier pads, and corrugated pads cut bruising losses 53 percent in transcontinental tests. The Washington State Apple Commission (36) reported on a stationary machine to simulate transit tests of various types of packing and their efficiency in reducing bruising.

Woodward (120) noted that railroad shipments may produce more bruising than truck shipments; but he recorded that the test shipments were to only one destination, were from one point of origin, and that his findings were true for a limited size shipment.

The question of what causes damage-in-transit to apples sometimes arises. A serious type of transit bruising of apples sometimes occurs in the bottom layers of boxes on the lower sides of the fruits. This often is thought to be due to freezing. Rose, McColloch, and Fisher (86) stated that apples both bruised and frozen in transit usually will show flattened areas, 1 1/2 to 2 inches in diameter, somewhat sunken and soft toward the center, and of a dull-brown or slate color over most of the surface. Transit bruises are smaller in diameter, flat instead of sunken, the skin covering them is not slate colored, and the flesh beneath is firm. In virtually all cases of severely frozen apples, sunken spots, about as deep as wide, develop at places that were bruised while the apple was still frozen. See also (42).

Bogardus and Burt (9) found that increasing the productivity of warehouse workers did not require rougher handling of produce. They found that men with good work habits could handle as many packages with care as poor workers who gave the produce rough and careless handling.

Herrick and co-workers cautioned that warehouse and platform floors should be kept free of holes and rough places. They observed that such damaged places not only slow down warehouse handling, but they also cause additional bruises on the produce when it is trucked over these areas (51).

Van Waes' (104) data showed that bruising of even carefully handled McIntosh apples increased from 33 to 49 percent from the warehouse to the retailer. It is not unreasonable that any additional handling or transportation produces additional chances for bruises to occur. Clowes (22) pointed out that most produce sold in New York City moved through at least two wholesalers or jobbers, and that a substantial quantity moved through three such handlers before reaching the retailer. Scott and Leed (89) reported that apples delivered directly by growers to retailers were 50 percent less bruised than were similar apples delivered by wholesalers. Perkins (78) also found less bruising occurred when bagged apples were delivered from the farm to the retailer directly rather than through warehouses. When apples 99 percent bruise-free were delivered directly to retail stores, they arrived with only 9 percent added bruising. When similar lots were moved to retailers through wholesalers, they arrived

with 40 percent added bruising. These figures indicate that additional means and care should be considered to lessen the bruising of apples in warehouses.

Retailing

Many retailers feel that since the apples they receive have numerous bruises it is pointless to handle the apples with additional care. This, of course, is not sound reasoning. Even discounting any progress by others in eliminating bruising, the retailer can easily bruise the apples he receives and thereby lower their quality, their shelf life, and their profit potential. The voluminous research reported in the preceding paragraphs on bruising have as their one main goal that the retailer shall be offered apples that are free of bruises, disease, and decay. If the retailer in turn fails to offer such apples to his customers, the efforts of all others in the apple marketing system also fail. Thus, the retailer, too, has an obligation to lessen bruising by his clerks and customers.

In 1949, Van Waes (104) reported that when McIntosh apples were not handled carefully about 85 percent of them were bruised by the time they reached the retailer. If carefully handled thereafter, at least 10 percent more were bruised before the apples reached the consumer. See also p. 137. In 1957, Schomer (88) reported that about one-third of the apples offered in retail stores in Michigan and in California were badly bruised. In 1963, Perkins (79) reported that about two-thirds of the apples on display were bruised: 51 percent slightly, 29 percent moderately, and 20 percent severely. He thought that about 50 percent of the total bruising, and about 70 percent of the severe bruising, occurs after the apples leave the farm. Woodward (119) reported that nearly 25 percent additional bruising occurs while apples are on display. Much of this occurs as retail clerks roughly dump apples into display bins, or as the apples are sorted or arranged in the display, but additional bruising is caused by consumer handling (47, 119). 9/

Woodward (119) also reported on apples displayed by various methods in retail stores. He found that the bruising per 100 apples averaged: 475 bruises for bulk apples displayed on counters, 406 for those in bushels, 410 in open packages, and 360 bruises in wrapped packages. Similarly, Scott and Leed (89) noted that in 204 retail stores in Cleveland, Canton and Youngstown areas, in 1949-50, apples in bulk averaged 46 percent more bruises than apples in consumer packages. It has been observed that open-tray packages encourage customers to handle apples unnecessarily (48), and that if the trays are cellophane overwrapped bruising is reduced (78).

Toothman and Anderson (101) describe equipment and give specifications for the tray-display of apples in retail stores. Such equipment allows clerks to arrange produce displays in the backroom under less hurried conditions than if the display must be arranged while customers are buying produce. This practice should lessen bruise damage to apples by clerks, as well as save time for the clerks.

To reduce both clerk and consumer handling, many retailers display apples in their original paper wraps. There is an association of wrapped apples with high quality, an association that customers seem to respect, and the customers

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9/ See also footnote 3, p. 134.

handle such fruits less often. Other retailers display their apples in short stacks of the original shipping trays lifted from the shipping cartons directly to the display counters. This eliminates further bruising by clerks and it lessens that caused by customers. 10/ See also Retailing in the section on Terminal Market Handling.

Advertising, as well as special bulletings, has had its part in selling bruise prevention to personnel. Corey (24) reported in 1962 that the Western New York Apple Growers Association had issued "pin-ups" for the backrooms of retail stores, using such slogans as "Treat me gently...," "I bruise so-o-o-o easily...," etc.

A novel attempt to reduce bruising from customer handling, and to increase sales at the same time, was an "apple marketing tree," designed as a food display to hold 60 five-pound bags of apples. The idea was tried in 97 stores in New York State in 1959. Its main disadvantage was its small size. Reduced bruising from customer handling was an advantage mentioned by 84 percent of the interviewed personnel (25).

Ceponis and Kaufman (19) reported that apples displayed in overwrapped trays had fewer bruises than apples displayed in bags or in bulk. When held 4 days beyond the usual retail period at 70° F., they also had less decay.

Lewis (58) observed that bruises on apples became badly discolored when the apples were displayed without refrigeration. When similar apples were refrigerated the bruises were not discolored. Fully ripe, badly bruised apples deteriorated much faster when displayed without refrigeration. See also (1, 29, 39, 52, 59, 85).

Supervision

In almost every survey on bruising causes, the importance of supervision is stressed. Bisno (6) found that bruised apples packed with sound ones can cause 200 times as much decay as when sound apples are packed alone. Washington State workers determined that the most important bruise prevention factor is packinghouse supervision (36). Apples carefully handled as a result of good supervision can be delivered to retail stores with one-half to one-third as much bruise damage as fruits not handled under careful supervision (36, 92, 104).

Packer rating systems have been used for years by some packing plants. Plants using packer rating systems for the first year usually have less satisfactory bruising scores than plants that have used the system for more than one year, but they rapidly improve (112, 113).

The supervision of packing operations has many facets. One of these that has direct bearing on apple bruising is the layout of the packinghouse. Williams and Blakeley (118) reported in 1959 on studies of the flow patterns of apples from storage to shipping areas in 39 packing plants. They pointed out that longer, indirect routes through the plants cause more bruising of fruits and add to the costs of handling through longer travel time, more confusion and congestion in the packing room. See also references (7, 96).

Perkins (78) suggested that a program for reduction of apple bruising in packinghouse and in shipping-point storages should especially include better

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10/ See footnote 3, p. 134.

packing and packaging techniques, improved containers and loading methods, palletized handling, closer supervision and educational programs.

Washington State has been outstanding in its educational efforts to produce higher quality apples and more profits for its growers. The main points of its quality control program have included: (a) A 2-year survey of the appearance and condition of apples in markets and a report of this information by colored slides at growers' meetings; (b) a movie film on careful picking, produced and shown for 3 or more years in theaters and schools throughout the State; (c) a method for rating pickers, by use of a standard apple sampler and a scoring system, to lessen picking damage; (d) cartoon films to show packing crews throughout the State, using data gathered from detailed studies of apple packing operations; (e) a method of rating apple packers to pinpoint packing care; (f) posters directed to workers to illustrate how to lessen bruising of apples; (g) simulated transit studies to find ways of improving the standard pack by use of pads and liners; (h) encouraged tray packs over standard packs; and (i) reduced rough handling in warehouses through use of mechanical stackers (35). Thus, Washington State workers, among others, have identified the sources of bruising of apples and have followed a program for correction (107, 111). It is believed that other educational programs likewise should be arranged to reach all workers in the trade (10, 78).

Hauck (47) wrote a fitting summary on the subject of bruise prevention: "Any effective program to provide apples with less bruising damage for the customer requires joint action. The grower, the trucker, the warehouseman, the deliveryman, the produce manager, and any others who handle apples, are involved. Neither grower nor anyone else in the marketing channels can do the job alone. A program to get cooperative action to reduce bruises would be well worthwhile. The wide range in bruising between better and poorer samples shows that considerable improvement is possible. This is true at the farm and at the retail store."

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MARKET DISEASES

Introduction

In this discussion a disease is considered to be any abnormal condition which detracts from the appearance or value or otherwise impairs the usefulness of apples. Market diseases are those found during the course of marketing. In this broad sense market diseases include those caused by infective agents such

as bacteria, fungi, and viruses, and those that have no infective agent, but are brought on by abnormal physiology or by injuries. Injuries may be grouped as mechanical, chemical, physical, and insect. Apples are, therefore, subject to many diseases. A number of diseases develop only in the orchard, but may be included in the packed fruit. Other diseases develop only after harvest. The origin of some can be traced to the orchard, whereas others are entirely independent.

Although some diseases, such as water core, that are associated with natural environment cannot be readily controlled, most diseases are controllable. In controlling apple diseases after harvest, emphasis is placed on good cultural practices, orchard control of diseases and insects, careful handling to avoid mechanical damage, chemical treatment where advisable, prompt storage and rapid cooling to the desired storage temperature, and proper storage environment, which for certain varieties is controlled atmosphere.

Only important diseases will be listed, and only those which have had additional research since 1945 will be discussed in detail.

Literature on the following diseases, which originate or develop in the orchard, are not reviewed: Apple cedar rust (Gymnosporangium juniperi-virginianae Schw.), bitter rot (Glomerella cingulata (Ston.) Spald & Schrenk), black pox (Helminthosporium papulosum Berg), black rot (Physalospora obtusa (Schw.) Cooke), fly speck (Leptothyrium pomi (Mont. & Fr.) Sacc.), fruit spot (Mycosphaerella pomi (Pass.) Lindau), quince rust (Gymnosporangium clavipes Cke. & Pk), and sooty blotch (Gloeodes pomigena (Schw.) Colby).

Recent literature was not found on some of the diseases that develop after harvest, such as fisheye rot (Corticium centrifugum (Lev.) Bres.), and side rot (Phialophora malorum (Kidd & Baum.) McColloch).

Of the physiological diseases, internal cork was omitted from the literature review because its control is part of production management. No recent literature was found pertaining to internal cork as a marketing problem. The literature on storage (superficial) scald and on bruising are reviewed in separate sections.

Fungus Diseases

Alternaria Rot (Alternaria tenuis auct.)

Alternaria rot is usually of minor importance on apples. The causal fungus, a weak pathogen, is always present in the orchard on dead and dying plant tissues. Injured or weakened apple tissues appear to be necessary for infection either in the orchard or after harvest. York Imperial apples with numerous slight cracks of the skin and lenticels often develop alternaria rot during storage.

According to Tweedy and Powell (168) [1/] alternaria rot has caused about 1 percent loss of Jonathan and Golden Delicious apples in Illinois each year since 1958. Fruit infection was always associated with an injury.

They identified the causal fungus as Alternaria mali Roberts and named the rot "cork rot" to distinguish it from the usual alternaria rot caused by Alternaria tenuis.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 180.

Roberts [2] described Alternaria mali in 1914 before the careful work of Wiltshire [3], Mason [4], Neegaard [5], and others, who since have laid a workable foundation for the classification of species of Alternaria. Roberts established Alternaria mali primarily because the spores had minute pointed spines on their surfaces. In the modern concept Alternaria tenuis auct. (as used by authors) is a broad species embracing many hiotypes whose characteristics fall within the concept for the species, yet may vary in chain length, spore size, or other details.

Neegaard [5] considers Alternaria mali synonymous with Alternaria tenuis. In following the present concept of Alternaria tenuis the problem of identifying the cause of alternaria rot of apples would be simplified by accepting Neegaard's synonymy.

Apple Scab (Venturia inequalis (Cke.) Wint.)

Apple scab is worldwide in occurrence. Although scab lesions are superficial they affect the grade and price of apples both at harvest and following storage. Affected fruit may or may not be distorted. Fruits with scab spots are unattractive in appearance and lose moisture faster than normal fruits, and scab spots open the way for decay by other fungi.

Scab infection takes place in the orchard, but established spots may enlarge and new ones form during cold storage. Scab that develops during storage is called "storage scab"; it develops from late-season infections in the orchard, but is not visible at harvest. Storage scab usually develops slowly during cold storage, but can appear at any time during the storage period. The new lesions appear as brown to shiny black depending on the variety of apple and perhaps other factors.

Phillips and others (131) found that scab development on apples was as rapid in controlled-atmosphere storage with 5 percent CO_2 and 3 percent O_2 at 38° F. as in normal storage at 32°.

An adequate spray program is effective in the control of all phases of scab (143).

Botryosphaeria Rot (Botryosphaeria ribis Gross. & Dugg.)

Fenner (54) described botryosphaeria rot in 1925, but apparently it caused little loss until after 1950.

In 1951 Clayton and Fink (43) reported botryosphaeria rot (also known as bot rot, white rot, and clear rot) to be the cause of minor losses in North Carolina. In 1952, Weaver (175) found that losses from botryosphaeria rot and black rot (Physalospora obtusa (Schw.) Cooke) caused much concern among apple growers in Maryland and neighboring States. Some fruits were completely rotted

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2/ Roberts, John W. Experiments With Apple Leaf-Spot Fungi. Jour. Agr. Res. 2:57-66. 1914.

3/ Wiltshire, S. P. The Foundation Species of Alternaria and Macrosporium Trans. Brit. Mycol. Soc. 18:135-160. 1933.

4/ Mason, E. W. Annotated Account of Fungi Received at the Imperial Bureau of Mycology. List II, Fascicle 1:1-43. 1928.

5/ Neegaard, Paul. Danish Species of Alternaria and Stemphylium. Oxford University Press. London. 560 pp. 1945.

on the tree by mid-September. Losses in orchards on the Eastern Shore of Maryland ranged from 10 to 75 percent. Varieties most affected were Golden Delicious, Grimes Golden, Rome Beauty, and Northwest Greening. Those moderately affected were Delicious, Stayman, and York Imperial; least affected were Arkansas and Winesap. Weaver (175) suggested that the abundant inoculum (spores) in the orchards, together with above-normal rainfall during August, may have induced the extensive botryosphaeria rot during 1952.

Eid and Heuberger (50) found the peak of spore production of *Botryosphaeria ribis* in the orchard occurred from June 1 to July 15. Optimum climatic conditions for spore germination were 100 percent relative humidity and a temperature range of 77° to 86° F. Apparently fruits were susceptible to infection from June first until harvest in October.

Wallace and associates (174) found that the amount of water-insoluble material in the pulp of Golden Delicious apples at different stages of maturity decreased with maturation. Susceptibility of the apples to *Botryosphaeria ribis*, *Glomerella cingulata*, and *Physalospora* spp. occurs at a specific stage. They suggest a relationship between susceptibility and reduction in water-insoluble materials.

Fulkerson (55) found that mature detached apples inoculated with *Botryosphaeria ribis* decayed more rapidly at 75° and 65° F. than at 85° and 55°. At the favorable temperatures of 75° and 65° a soft, bleached rot usually occurred, whereas, at 85° and 55° a firm, brown rot was produced.

Lewis and Shay (85) reported botryosphaeria rot causing serious losses in southwestern Indiana in 1950 and 1951. Sound appearing fruits at harvest rotted rapidly at room temperature. In some cases fruits rotted after they were packed and sold.

Several investigators (67, 85, 136, 140) have reported substantial reduction or control of botryosphaeria rot in the orchard and after harvest by the use of certain fungicidal sprays.

McColloch 6/ found that fruits with the early (speck) stage of botryosphaeria rot, which appeared to be arrested at harvest, did not develop at 32° F., but a considerable percentage developed decay after they were removed from cold storage. Tests on agar indicated that the fungus made no growth at temperatures below 45°.

Blue Mold Rot (*Penicillium expansum* Thom)

During the years that spray residue removal was a serious problem, and vigorous washing measures were used in the Northwest, blue mold rot, especially at the lenticels was a serious problem.

English and others (52) found that fruits packed while wet developed no more decay than those packed dry. They reported that lenticels and washing injuries constituted the principal avenues of infection in dual-process washed apples and that a severe washing process increased both the number of open lenticels, as indicated by dye tests, and the number of lenticel infections. Passing apples through a heavily contaminated washing solution followed by a clean rinse caused only a slight increase in amount of decay. If, however, contaiminated apples were not rinsed, decay was greatly increased. They found

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6/ McColloch, L. P. Unpublished data. 1953.

that apples held in cold storage for 6 to 10 weeks before they were washed had developed a resistance to washing injury and decay.

In 1948 English (51) reported that the use of sodium chloro-orthophenylphenate (Dowicide-C) used in a rinse or in an alkali wash reduced blue mold and gray mold rot by 80 to 95 percent on wounded, inoculated apples. Bull's-eye rot, however, was not reduced.

Elaborating on decay control in the Northwest, English and others (53) recommended the addition of Dowicide-C to the sodium silicate washing solution. With this method, Dowicide-C at 1.2 percent concentration, followed by a fresh water rinse, did not cause injury and reduced blue mold and gray mold rot 18 to 20 percent. If used as a final rinse at 0.4 percent, Dowicide-C reduced total rot 43 to 75 percent. They mentioned the incompatibility of the chemical with acid and warned that Dowicide-C was irritating to workers and could cause a form of dermatitis.

Wright and Smith (182) studied the relation of bruising and maturity of Delicious apples to blue mold rot. They found that mature apples were much more susceptible to the blue mold rot fungus than immature fruits when bruised and inoculated. Fruits inoculated immediately after bruising were much more susceptible to infection and decay than similarly treated fruits that were bruised but stored for several weeks before inoculation. They also showed that bruised, inoculated fruits that were cooled slowly and were stored at 35° F. developed appreciably more decay than quick-cooled fruits stored at 32°. (See also section on Bruise Control.)

In 1962, Eckert, Kalbezen, and Sleesher (47) reported that an aqueous solution of 0.5 percent 2-aminobutane salt provided better control of penicillium rot on apples dipped for 1 minute than a comparable solution of sodium o-phenylphenate.

Apples are sensitive to certain chemicals and may be directly injured or have the flavor impaired. (See Chemical Injury, p. 166.)

Beraha and others (18, 19) reported that if Jonathan apples were inoculated with Penicillium expansum Thom and incubated 24 or 96 hours prior to irradiation that a minimal gamma ray dosage of 100,000 rep (roentgen equivalent physical) was required to arrest the progress of decay when held for 6 days at 70° to 95° F. Inoculated apples held 10 days before irradiation required 200,000 rep to arrest decay. Neither dosage caused visible injury to the apples.

Bull's Eye Rot (Neofabraea malicorticis Jacks. and N. perennans Kienh.)

In this review the term bull's-eye rot of apples refers to the decay caused by two closely related fungi Neofabraea malicorticis and N. perennans. In addition to the fruit rot, the fungi cause serious cankers on apple trees in certain localities.

These fungi have been reported as causing disease in California, Illinois Idaho, Maine, Massachusetts, Oklahoma, Montana, Washington, and Oregon. The disease is of economic importance, however, only in the Northwest.

Tree cankers are the source of spores for fruit contamination or infection which may later develop into bull's-eye rot.

Kienholz (82) lists three conditions necessary for infections of susceptible apple varieties: (1) adequate source of spores in tree cankers; (2) sufficient rainfall to wash the spores over the fruits; and (3) rainfall persisting long enough for spores to germinate and cause incipient infection.

Recent research, both in the United States and abroad, emphasizes the effectiveness of fungicidal sprays in the orchard in reducing or controlling bull's-eye rot after harvest (13, 28, 29, 42, 72, 82, 181).

The use of chemical formulations including either sodium chlororthophenylphenate (51) or sodium orthophenylphenate (82) as a postharvest dip of apples and pears has not been effective as a control of bull's-eye rot.

Bull's-eye rot may develop at cold storage temperatures or after the apples are removed from storage. The infection can occur through injuries, but usually occurs through open lenticels. By the periodic loading of fruits with spores after harvest, Edney (48) showed that fruit resistance declined with the length of storage. In some countries the rot is known as "ripe spot" (28).

Pierson (132) points out that tree props and rainy weather may interfere with fall spraying and thus permit late season infection. To aid in the orderly marketing of fruits suspected of having incipient infection, Pierson (132) developed a technique for forecasting bull's-eye rot. The technique consisted of holding grower-lot samples at temperatures of 65° to 80° F. under high humidity and thereby speeding up the development of rot. Apples considered to be a poor long-term storage risk could then be marketed before decay developed.

Gray Mold Rot (Botrytis cinerea Per. ex Fr.)

Gray mold rot may occur wherever apples are grown. In general, the disease is not a problem of stored apples in the Northwest, except at times in the humid districts.

In the eastern United States gray mold rot has in the past been an important disease of stored apples (142). However, there has been a reduction of gray mold rot on stored apples in recent years. Possibly the protective action of some of the organic fungicides currently used as cover sprays is carried over into the storage period.

Investigators in the Northwest have reported (51, 83, 133) effective control of gray mold rot on pears by chemical treatment after harvest. Similar studies on apples have not been made.

Miscellaneous Storage Rots

Gloeosporium Rots (Gloeosporium spp.).--The gloeosporium rots in the United States are known by their common names as bitter rot (*Glomorella cingulata* (Ston.) Spauld. & Schrenk) and bull's-eye rot (*Neofabraea perennans* Kienh. or *Neofabraea malicorticis* Jacks.). Bitter rot occurs east of the Great Plains, especially in hot, humid areas. It is primarily an orchard disease and its control depends on an effective spray program. Bitter rot is occasionally found on apples in storage or during marketing where the apples failed to cool quickly and incipient infections developed decay. The fungus makes little growth at 50° F. or below.

Bull's-eye rot occurs primarily in the Pacific Northwest, but has been reported from certain other States. (See Bull's-eye Rot, p. 163.)

A storage rot of apples caused by *Gloeosporium album* Osterw. was first reported in Germany in 1907. Since then the disease has been reported as an important cause of loss of stored apples from most apple-growing countries of Europe. In addition, the disease has been reported from Australia, New Zealand, South Africa, and Canada.

There is general agreement that an adequate spray program in the orchard greatly reduced gloeosporium rot during storage (22, 23, 49, 62, 89, 101, 141, 144, 156, 177).

Burchill and Edney (36) found that decay of Cox's Orange Pippin apples during storage was determined by maturity (ripeness) of the fruit rather than by the quantity of inoculum present on the fruit.

Montgomery (109) found that rot caused by *Gloeosporium album* was much more extensive on apples in cold storage than on those in controlled-atmosphere storage. If the rot was due to Gloeosporium perennans, however, the reverse was true.

In trials with an air washing apparatus in cold and gas storage, Hansen (64) found the effect mainly one of raising the humidity. Gloeosporium rot increased as humidity increased.

Jamalainen (76) also reported losses from gloeosporium rot were heavy in storages with high relative humidity.

Nyhlen (118) reported extensive gloeosporium rot on 5 varieties of apples stored at +2° to 3° C. (35.6° to 37.4° F.). These temperatures are considerably higher than the 31° F. storage temperature recommended in the United States for most varieties of apples.

Moldy Core, Carpel Discoloration, and Core Rot.--Moldy core and carpel discoloration affect varieties with open calyx tubes. A variety of fungi have been isolated from moldy cores in different parts of the world.

Mouat (110) found *Neofabraea perennans* the principal cause of moldy core of Delicious apples in New Zealand. He stated that moldy core could be controlled by following the recommended spray program.

Miller (105) isolated *Fusarium* sp., *Botrytis* sp., and *Alternaria* sp. most frequently from affected carpels of Wagener and Red Delicious apples. He reproduced carpel discoloration by injecting these fungi or by injecting certain spray materials especially when the material included a wetting agent. Miller (106) suggested that dry weather in late spring or early summer may cause the calyx tube to remain open. Heavy rains late in the season would favor fungus development.

Taylor (163) found the black rot fungus, *Physalospora obtusa* (Schw.) Cke., most prevalent as a cause of core rot of Red Delicious grown in Georgia.

Pyrenochaeta Rot (Pyrenochaeta mali M.A. Sm.).--Pyrenochaeta rot (148), a new disease, was found on a Rome Beauty apple grown in Washington. The original specimen showed small dark drawn spots centered around lenticels. Apples inoculated through wounds and incubated at about 60° F. slowly developed decay. Apples dipped in a spore suspension failed to become infected through normal lenticels. It would appear that infection followed some kind of injury at the lenticels in becoming established in the original specimen. The *Pyrenochaeta* fungus is not expected to become an important apple fruit pathogen.

Stemphylium Rot (Stemphylium spp.).--Several species of *Stemphylium* have been reported as causing a rot of stored apples both in Europe and the United States. Certain species develop the perfect stage which aligns them with the genus *Pleospora*.

Stemphylium rot usually develops on injured or weakened tissues and is of minor importance. Lesions are small to medium size, brown to nearly black, moderately firm due to the spongy texture of decayed tissues, and nearly indistinguishable from alternaria rot.

Behr (17) reported stemphylium (*Stemphylium botryosum* Wallr.) in 1960 for the first time in Germany. Susceptibility of apples increased with ripeness.

Chemical Injury

Apples readily absorb undesirable odors. If stored in the presence of any foreign odor the flavor of the fruits will be impaired or even ruined. For cleaning the storage rooms, the safest recommendation is to scrub the floors and white-wash the walls and ceiling. In cleaning field or storage boxes, steam is effective and leaves no odor.

Very little has been publised about chemical injuries. Ginsburg (61), however, reported that browning occurred on fruits that came in contact with wood of boxes that had been treated with copper sulfate. He also found that treatment of bulk bins with wood preservatives caused tainted fruits.

Virus Diseases

About 15 virus diseases affecting the apple are known to occur in apple-producing areas of the world. Most of these occur in Europe.

Atkinson and Robbins (9) reported a virus disease known as green crinkle, which affects only the fruits, occurring in all important apple districts of New Zealand.

Since 1945 established virus diseases in the United States, such as mosaic and stem pitting, have continued to spread and new virus diseases have been found (9, 77, 87, 107, 108, 125, 134, 135, 137, 138, 149).

Certain viruses affect the quality and grade of the fruits. Examples are russet ring, star crack, scar skin, and dapple apple. Affected fruits show the blemishes at harvest and the condition does not change during storage or marketing.

Physiological Diseases

Bitter Pit

Bitter pit, also known as stippen in Germany and as Baldwin spot on that variety in the United States, is a physiological disease of certain varieties of apples. Bitter pit was first described in Germany in 1829 and is worldwide in occurrence.

Typical bitter pit starts at the calyx end of the apple as relatively small, round to angular indentations in the surface. The depressions are usually subtended by a small, more or less round mass of dead spongy tissues. Sometimes, especially in certain varieties, spongy masses of dead tissues occur deeper in the flesh. Often the spongy tissues shrink because of loss of moisture, and a cavity is formed. Some varieties such as Summer Rambo, Gravenstein, and Arkansas, which are highly susceptible to bitter pit, may develop pits nearly to the stem end. The surface of the pits may at first be deeper colored than normal but upon standing the color changes to grayish brown. The largest pits eventually become brown to black. Pits on certain varieties such as Yellow Newtown, Winter Banana, and Baldwin are larger than those described above and tend to be round with flat bottoms.

In the United States commercial varieties that are quite susceptible to bitter pit are as follows: Summer Rambo, Gravenstein, Baldwin, Northern Spy, Grimes Golden, Rhode Island Greening, Delicious, Stayman, Arkansas, and Yellow Newtown. York Imperial has at times been listed with susceptible varieties, but it is purposely omitted here. At times York develops true bitter pit either

while the fruits are on the tree or after harvest, but the variety is not highly susceptible. The York variety is highly susceptible, however, to a disorder that has been known for many years as York spot. Unlike bitter pit, which at times develops while apples are on the trees, York spot develops entirely while the fruits are on the trees. This disorder has been considered by some to be bitter pit, but it will be discussed separately under the subheading Cork Spot (York Spot).

Next to scald there has probably been more research on bitter pit than any other physiological disease of apples. Martin (93) made a comprehensive review of publications, between 1935 and 1959, which pertained to bitter pit. He divided the research into four groups. In 1961 van Schreven (171) also prepared a digest of literature. She followed Martin's plan with some elaboration. These reviews have been fully utilized here.

In 1934 Barker (12) reviewed 209 papers published during the previous 65 years. He concluded that there was no decisive information on the causal factors of bitter pit, and that only certain characteristics of the disorder were known. Some predisposing factors that were almost universally accepted were: (1) liability to develop bitter pit after harvest decreased with increasing maturity at harvest (without an equivalent amount of bitter pit developing while the fruits were on the tree); (2) susceptibility increased with increasing fruit size; and (3) fruits from light crops, from young and vigorous trees and those given heavy nitrogen dressings had high susceptibility. Less conclusive results were obtained on factors such as rootstock, soil conditions, manuring (other than nitrogen), pruning, thinning, and climatic and storage conditions. Research continued along these lines for a time after 1935, confirmed previous research, but made no major advances. This area of research constitutes Martin's first group.

The second group of research involved greater precision than the first and also the use of new techniques. Sod culture or mulch gave less bitter pit than clean cultivation (68, 78, 88, 113, 159). Fruit size was closely correlated with bitter pit (2, 27, 90, 91, 92).

The histology of bitter pit lesions was studied and compared to those of boron deficiency. Skin coatings (63), prompt storage, and controlled-atmosphere storage (95) were reported to reduce bitter pit, but a careful evaluation indicated that these treatments delayed the appearance of bitter pit but did not necessarily reduce the final incidence. After 1935 there was more general agreement that water stress, particularly during the latter stages of development and on larger fruits was an important factor. Experiments with irrigation, mulching, and humus supply gave evidence that a regular water supply lessened the incidence of bitter pit (73).

The competition for water between leaves and fruits was demonstrated and the osmotic values of each were studied. 7/ In 1950 these studies were summarized by Heinicke (66) in considering the predisposing factors of apples to bitter pit. In 1959 Woodhead (180) also summarized conditions that influence bitter pit development.

In Martin's third group of research, he reviewed literature that reported tests with boron as a possible control of bitter pit. Results between 1935 and 1945, where boron was added to the soil or injected in the trees, were mostly negative (8, 84, 139).

7/ Smock, R. E. Studies on Bitter Pit of the Apple. N. Y. (Cornell) Agr. Expt. Sta. Memoir 234, 45 pp. 1940.

Since 1945 workers in the Netherlands (1, 79, 111, 112, 113, 160, 161, 176) have made new tests using sprays of borax and obtained reductions in incidence of bitter pit. This work showed that the time of application of boron was critical and reductions occurred only when treatments were applied over a short period at about the time of full bloom. Spraying outside this period might increase bitter pit (161). On other soil types in the Netherlands, however, these results could not be repeated (113). Boron sprays at time of bloom did not reduce or control bitter pit in tests conducted in widely separated parts of the world by Bould and Tolhurst (25), Martin and Carne (94), Smock and associates (153), Southwick (155), and Melville and Hardesty (104). Martin, Lewis, and Cerny (97) did not try boron alone but got no benefit by adding boron to calcium nitrate sprays.

After 1945, workers in the Netherlands switched their research from boron to other minerals. They confirmed Brown's (30) observation that fruit with bitter pit had a low phosphorous content and thought that this was due to magnesium deficiency (113, 114, 115, 116). Later, Netherland workers reported that bitter pit was associated with high potassium content of the leaves (160, 162) and fruits (171).

Continuing this review Martin states, "Dunlap and Thompson found that sprays of boron applied at full bloom gave a response, but there is doubt that the disorder in this case was similar to that recognized as bitter pit in Australia" (46). (See Cork Spot.)

The real turning point in gaining a measure of understanding and control of bitter pit started with investigations on the relation of calcium to the disorder. This came about slowly following the unexpected results of DeLong in 1937 (44). He analyzed the ash content of apples affected with "blotchy cork," a type of bitter pit. At the time of the analysis, emphasis was on the newly discovered boron deficiency. It was thought that perhaps a high calcium content was preventing assimilation of boron and thus causing bitter pit. Instead, the affected apples showed a low calcium content. About 20 years later a study was made on calcium deficiency in relation to bitter pit.

This study was made by Garman and Mathis (56) on the effect of calcium on "Baldwin spot" (bitter pit). They reported that the disorder was related to an unbalanced nutritional condition. They concluded that calcium was the critical element and that an imbalance between calcium and magnesium or between these and potassium was definitely related to the occurrence of bitter pit. They also found a definite connection between the amount of bitter pit and the leaf to fruit ratio of calcium. They state that excess nitrogen can easily prevent a favorable balance through promotion of increased potassium and magnesium in the fruit. They stated that efforts to control bitter pit through calcium sprays were partly successful, but that much more research was needed. A considerable amount of research was stimulated by their discussion of unbalanced nutrition and bitter pit.

In 1960, Martin, Lewis, and Cerny (97) studied the effect of calcium and magnesium sprays on the occurrence of bitter pit in the Cleopatra (Ortley) variety. They found that magnesium nitrate increased pit, whereas, calcium nitrate decreased it. Calcium dihydrogen phosphate had no significant effect with or without borax. They indicated that borax may have reduced the effectiveness of calcium nitrate. They agreed with Garman and Mathis (56) that calcium was the critical element and that an unbalanced condition lies between calcium and magnesium. There was, however, no evidence from their results that potassium or phosphorous were involved.

Askew and associates (4, 5) in New Zealand sprayed Cox's orange apples about mid-December and mid-January with calcium acetate, potassium, and sodium and with superphosphate and borax in an attempt to control bitter pit. Orchards on two soil types were used. Sprays altered the chemical composition in both fruits and leaves in minerals and in amount of sugars and acids. In one season calcium sprays highly significantly reduced the amount of bitter pit in one orchard, but not in the next season. In the second orchard calcium sprays gave best results, but the treatment was not significantly beneficial. Potassium, sodium, and magnesium were detrimental and increased the incidence of bitter pit.

Askew and associates (6, 7) reported that total ash content of the fruits was significantly positively related to increasing incidence of bitter pit. High values of the ratios Mg/Ca, K/Mg, K/Ca, and K/N accompanied high incidence of bitter pit in the fruits.

In studies on leaf analysis van Der Boon and associates (169) found that bitter pit increased as the K/Ca ratio in the leaves increased.

Bouhier (24) showed that bitter pit in apples was strikingly associated with high values of the ratio of K + Mg/Ca in harvested fruits. The disorder was not found in Grimes Golden, Winesap, or Golden Delicious in which the ratio was below 22. In Belle de Boskoop and Reine des Reinettes bitter pit occurred in fruits with values of 28 to about 35, but not in those with 23 or lower. In Cortland with an average ratio of 53, bitter pit was very severe.

Oberly and Kenworthy (120) reported that under Michigan conditions an increase of boron in the leaves and mature fruit tissues may increase the incidence of bitter pit. The incidence of bitter pit increased as size of fruit, leaf boron and potassium, and fruit boron, potassium, phosphorous, and nitrogen increased. Conversely, the incidence of bitter pit decreased as leaf magnesium and manganese, and fruit calcium and manganese increased.

Martin and associates (100) found that if calcium was withheld from trees of the Sturmer variety the fruits became highly susceptible to bitter pit. Fruit content of nitrogen, potassium, phosphorous, and magnesium was high and calcium was low. The molar decrease in calcium was much less than the molar increase in the other elements. They found no evidence of a disturbed balance between the elements in the fruit. Ratios of magnesium to calcium or of magnesium and potassium to calcium emphasized the differences between fruits with low calcium and fruits with normal calcium. However, these ratios did not have any physiological significance, and they may detract from important predisposing factors such as the increase in nitrogen and rate of respiration (96). When magnesium was withheld, the incidence of bitter pit was not significantly different from that of fruits that received a complete fertilizer. The results obtained from withholding magnesium further emphasize the specific importance of calcium in the fruit physiology. Pitted fruits on trees that were adequately supplied with calcium appeared to be the result of localized deficiencies of calcium.

Kidson (81) found about four times as much calcium in the skin of apples as in the underlying flesh. Healthy and pitted fruits from a number of orchards showed a consistent relation between pitting and low calcium levels in the skin and flesh.

Yamazaki and Mori (183) reported that fruits from trees grown in solution culture for 2 years without calcium were severely affected by bitter pit. A lack of magnesium did not produce pit. Under similar culture Yamazaki and others (184) reported that the incidence of bitter pit at harvest was severe on Jonathan apples supplied with high nitrogen. Bitter pit increased significantly as the calcium supply decreased.

Melville and Hardesty (104) applied calcium nitrate and boron sprays in three orchards in a season of severe bitter pit. Varying, but encouraging, results were obtained with calcium nitrate sprays. No benefit was found from boron sprays.

Smock, Fisher, and Forshey (153) applied boron and calcium sprays to Baldwin, Northern Spy, and Rhode Island Greening. Boron and calcium acetate sprays failed to reduce bitter pit. Calcium nitrate and calcium chloride sprays, however, reduced bitter pit, in some tests highly significantly so. They state that the present thinking is that pitting is probably induced in the orchard by competition between leaves and fruits for calcium. It is apparently not a simple calcium deficiency problem, but a complex relationship between elements like calcium, magnesium, potassium, and nitrogen.

Chittenden (41) applied foliar sprays of the acetates of sodium, potassium, calcium and magnesium, sodium borate, and iron chelate to Cox's Orange Pippin. Calcium and magnesium acetate slightly reduced the incidence of bitter pit, but potassium and sodium acetate greatly increased pitting. Borax and iron chelate very slightly increased pitting. Ground limestone at 4 tons per acre increased pitting, but gypsum applied at the same rate had no effect.

Beyers (20, 21), in South Africa, found calcium nitrate and calcium chloride equally effective in reducing the incidence of bitter pit. Best results were obtained with three sprays of calcium nitrate, at 14-day intervals, beginning in mid-December for Golden Delicious and Starking and beginning in early January for White Winter Pearmain.

Jackson (74, 75) tested sprays containing calcium, magnesium, potassium, phosphate, nitrogen, iron, strontium, tungsten, and vanadium. Only calcium nitrate significantly reduced the incidence of bitter pit during storage. Both tree sprays and postharvest fruit sprays of this compound consistently reduced the disorder. Later sprays tended to be more effective than early ones, but the most effective treatment was calcium nitrate (6 pounds per 100 gallons of water) applied at 14-day intervals throughout the season. No damage occurred.

Hilkenbaumer and O'Daniel (69) found a marked decrease in bitter pit and decay, after storage, in apples from trees sprayed with 0.2 to 1.0 percent calcium nitrate and 1.0 percent calcium chloride. Two sprays of calcium nitrate, the first applied 4 weeks before harvest gave the best results.

Van Schreven and associates (173) were able to reduce bitter pit by 75 percent in Cox's Orange Pippin by five applications of calcium nitrate. A postharvest dip in a solution of 0.75 to 1.0 percent calcium nitrate reduced pit by only 30 percent.

Buchloh (31) reported that spraying trees with calcium nitrate reduced the incidence of bitter pit to 6 percent, whereas a fruit dip in a 1 percent solution reduced the incidence of bitter pit only to 41 percent compared to 71 percent in untreated fruits.

Baxter (14, 15, 16) has published an excellent review of bitter pit and also an account of his work in Australia where bitter pit is most prevalent on Cleopatra, Delicious, and Gravenstein.

In all cases, calcium sprays were effective in reducing bitter pit at harvest, and if the sprays were also applied shortly before harvest, they were effective in reducing pit in stored fruits. Calcium nitrate slightly delayed maturity and reduced the red color of the apple, so that for red varieties calcium chloride is recommended. Soil application of calcium nitrate was less effective than sprays in the control of bitter pit, but a combination of both appears superior to the use of sprays alone.

For control of bitter pit on green varieties, Baxter recommended: Calcium nitrate 8 pounds per 100 gallons of water with a wetting agent. Spray once or twice within 6 weeks of petal fall and again within a month of harvest. For red varieties the early season sprays could be calcium nitrate, but later sprays should be of calcium chloride 5 pounds per 100 gallons. He (14) found that covering the fruits during spraying did not reduce the effectiveness, but painting calcium salts on the fruits was more effective than foliar sprays.

Wilkinson (178) published a brief review of the bitter pit problem with special reference to control of the disorder in England. Bitter pit is a problem there only about 1 year in 5, and calcium sprays are not recommended as a general practice. Instead, fruit growers rely on approved orchard practices, proper picking maturity, and prompt cooling of the fruits.

Results with calcium sprays for reducing bitter pit on apples from mature apple trees have in general been favorable throughout the world. Stevenson (158), however, in Australia reported that preharvest sprays of calcium chloride and calcium nitrate failed to reduce the incidence of bitter pit significantly on apples from young trees. All sprays caused some injury to the trees. The effect of fruit maturity on the incidence of bitter pit was significant. Calcium sprays are not recommended for the control of bitter pit in fruit from young trees.

Recent investigations on bitter pit have also covered certain areas other than calcium nutrition. One that is of considerable interest in a report pertaining to the possibility of bitter pit being caused by a virus. In 1933, Atanasoff [8/] published a paper on bitter pit and raised the question of whether the disorder was caused by a virus. While the virus theory has not been accepted, published research on the subject had been lacking. In 1962, Campbell and Luckwill (38) published the results of their transmission experiments with bitter pit conducted in England. They concluded from grafting tests that bitter pit is very unlikely to be a virus disease.

Research has also continued on certain factors in the orchard and their relation to bitter pit.

Bünemann (33) found that pitted tissues had less calcium and more magnesium than normal tissues.

Bünemann (35) also found that tissues of Northern Spy apples affected with bitter pit had twice as much nitrogen as apple tissues that were free of bitter pit. Hill (70) found a highly significant positive relation between foliage nitrogen and the incidence of bitter pit. Nyhlen (117) reported that late applications of nitrogen increased the amount of bitter pit.

Luchetti and Ferrigato (86) attributed the absence of bitter pit, in the Ferrara (Italy) region, in 1961 to the very dry summer and autumn. On the other hand, Nyhlen and Rootsi (119) found more bitter pit, during dry years, in apples from nonirrigated trees than from irrigated ones. The lowest incidence of pit occurred in plots with balanced nitrogen and phosphorous with or without potassium. Straw mulch appeared to favor pit in comparison with clean cultivation. Incidence of pit did not appear to be related to size of fruit or extent of crop per tree. The last two statements are in disagreement with the findings of other researchers.

Butijn and Van't Levin (37) reported less bitter pit in irrigated than in nonirrigated fruits of Cox's Orange Pippin.

8/ Atanasoff, D. Bitter Pit of Apples: a Virus Disease? Yearbook of Agriculture 12:31-67. Sofia, Bulgaria. 1933.

Keijer and Dijksterhuis (80) reported that apples that were most subject to scald were also most subject to bitter pit.

Sorensen (154) found that heavy pruning increased bitter pit.

Some recent studies have been made on the cytology of pitted tissues. Working with Winter Banana apples Arnaud (3) found that bitter pit tissues are not corky in nature, but are probably the result of disturbances of the dehydrogenase enzyme system. He also states that bitter pit symptoms can be masked by zinc applications.

Buchloh, Baxter, and Neubeller (32) reported that starch grains remained in the area of bitter pit tissues in Cox's Orange Pippin long after it had disappeared elsewhere. They stated that in the early stages of bitter pit the fibers in the cell wall break down, and there is an aggregation of droplets which in healthy tissues are scattered through the cytoplasm. Pitted tissues had a higher percentage of certain fatty acids than healthy tissues.

In studying the effect of fungicidal sprays in France, Paulin and Anquez (126) noted that bitter pit was most common on Reinette du Mans apples treated with ziram or zineb.

Ginsburg (60), in South Africa, reported a relatively reliable method for detecting pit-susceptible apples. The sample of apples is subjected to 90° F., in an atmosphere of 1 percent acetylene for 48 hours. The development of bitter pit from a latent stage is accelerated by the treatment.

Brown Core

Brown core, also known as core browning and in Australia as "core flush," is a physiological disease of certain varieties of apples. In the United States brown core occurs principally in New York and New England. The disorder is most serious on McIntosh, but Baldwin, Rhode Island, and Twenty Ounce may be affected.

Smock (150) offered additional data to indicate that brown core is a low-temperature disorder and that susceptibility varies each year. He also found that limb shading greatly increased the disorder but that shading individual fruits or defoliating limbs had no effect. Nitrogenous fertilizers in some years increased brown core in storage. Smock (150) states that susceptibility to brown core in McIntosh apples is reduced by advanced maturity or by a delay in reaching cold storage. Padfield (122) also reduced brown core (core flush) in Granny Smith apples by a delay before refrigerated storage. He considered the required delay too long to be practical, however.

Smock and Blanpied (152) compared controlled atmosphere storage and film-box liners on the incidence of brown core in several varieties of apples. Neither controlled atmosphere storage at 38° F. nor the use of sealed film liners at the same temperature controlled brown core in Baldwin or Rhode Island Greening. Results on brown core in McIntosh were inconsistent in 1956 and 1957. (See also section on Controlled-Atmosphere Storage.)

Phillips and Poapst (129) found that the seed physiology affected core flush (brown core) in McIntosh apples. For example, seeds that germinated in the shortest period following 6 months' storage were from fruits with the greatest amount of brown core. They conclude that brown core could be reduced if seed activity could be controlled.

Phillips, Poapst, and McQueen (130) reported that core flush (brown core) was reduced during 5 months' storage at 32° F. from an index of 105.3 to 17.0 and superficial scald held to zero if McIntosh apples were exposed to 85,000 rad of gamma radiation.

Cork Spot (York Spot)

The term cork spot has been proposed by a committee from the Cumberland-Shenandoah Fruit Worker's Conference to replace the term York spot. The condition widely known as York spot is probably as old as the York Imperial apple, and the term has been in the literature since 1915. 9/

The need for a change in name stemmed from several sources: (1) A certain amount of confusion was attached to the term York spot, due in part to the poor original description and in part to the view held by some that York spot is the same as bitter pit; (2) recent research has shown that the occurrence of York spot has been reduced on York Imperial apples by timely boron sprays, but not by calcium sprays, whereas bitter pit was reduced on susceptible varieties by calcium sprays, but not boron sprays; and (3) a condition similar to York spot has been found on certain other varieties, thus impairing the usefulness of a varietal name for the disorder.

Cork spot (York spot) is most prevalent on York Imperial apples, a variety grown mostly in Virginia, West Virginia, Maryland, and Pennsylvania. At times a similar disorder occurs also in the same locality on Delicious, Golden Delicious, Stayman, Grimes Golden, and Jonathan. No research has been published on the disorder on these varieties, however. The varieties listed as being subject to cork spot are also subject to ordinary bitter pit and develop typical symptoms.

Cork spot like bitter pit is induced by soil moisture stress, which creates a complex disturbance in the nutritional balance. Until research proves cork spot and bitter pit to be the same disorder, it seems best to consider them separately because of the difference in the symptoms and responses of the disorders to treatment.

Cork spot develops entirely in the orchard during the growing season and the external appearance does not develop or change after harvest. The first symptoms show as slightly flattened areas that appear somewhat water-soaked due to the tissues being greener or more purple than normal depending on the color of the fruits.

Reed and Crabill 9/ noted the appearance of the spots first during August. Some think that they appear earlier. Seriously affected fruits become somewhat distorted as they grow. If a fruit has a single spot or a few scattered spots, the external appearance is that of one or more flat-bottom or dimple-like pits. Sometimes a single pit is centered around a lenticel that is enlarged and prominent. In the past this symptom was perhaps mistaken for the feeding puncture of a sucking insect, and the condition was often identified as stigmonose. Since stigmonose seems to have lost its original application the term now appears to have little or no usefulness. Cork spot can appear anywhere on the fruit and the skin in the pits usually does not turn brown or black. Pits have brown corky areas either below the affected peel or somewhat deeper. In seriously affected York Imperial apples, corkey tissues occur in relatively large areas up to one-fourth inch in diameter or somewhat larger and may be located near the surface or half way to the core.

Published data concerning cork spot are somewhat limited. In 1959 Dunlap and Thompson (46) published results of a study, entitled "Effect of Boron Sprays

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9/ Reed, Howard S., and Crabill, C. H. The York Spot. Va. Agr. Expt. Sta. Ann. Rpt., pp. 50-51. 1915.

on the Development of Bitter Pit in the York Imperial Apple." Although the title included the term bitter pit, they were working with York spot or cork spot. They reported a marked reduction in occurrence of external and internal symptoms of the disorder as a result of timely sprays with boron. Sprays made of 1 to 8 pounds of solubor to 100 gallons of water were applied at full bloom and in some plots at various intervals thereafter. Apparently, nothing was gained by using more than 1 pound of solubor. They found that the spray must be applied at blossomtime to be effective. Although timely spraying gave effective control, they emphasized that the disorder was not completely eliminated.

Hewitt (65) found that the application of boron at or shortly after full bloom, did not affect the translocation or distribution of endogenous carbohydrates. Neither was there any effect on carbohydrate movement induced by different leaf: fruit ratios, by the boron content of the tree, or by limb girdling. High temperatures in 1959 increased the translocation of labeled sucrose to the shoot tips. It is concluded that the effect of boron sprays in reducing the incidence of bitter pit (York spot) cannot be due to their effect on sugar translocation.

In 1961, Thompson and Rogers (164) summarized four season's tests with solubor applied as three sprays starting about the time of bloom. When unsprayed trees had 53 to 83 percent cork spot in experimental work, boron sprays reduced the incidence to a range of 17 to 26 percent. In orchards where cork spot on unsprayed trees involved only 30 to 35 percent of the fruits, no effect was achieved with boron sprays.

Williams (179) found that foliar sprays of boron applied at full bloom and one week later consistently reduced the incidence of York spot (Cork spot), but the reduction was not always significant. Calcium chloride sprays were tested in one season and gave consistent, but not significant, control when applied several times from early season to midseason. The addition of calcium nitrate to boron sprays did not improve the control of York spot (Cork spot) by boron. Early to midseason sprays of calcium chloride combined with boron were more promising than early-season sprays of boron alone.

He reported that York spot became serious when the trees were ringed, and that it was reduced when the trees were partially defoliated. He also stated that treatments which affected the tree-soil moisture balance generally did not affect the incidence of York spot. The latter statement is in disagreement with the current opinion held by others. The statement appears also to contradict the results reported where some trees were partially defoliated if the assumption is made that partial defoliation reduces the competition between leaves and fruits for water.

In comparing cork spot and bitter pit, Mattus (103) stated that some researchers believe that cork spot results from water-stress conditions early in the growing season while late-season water stresses cause injury that finally shows up as bitter pit after harvest.

Bramlage and Thompson (26) applied boron sprays to Jonathan, Stayman, and Golden Delicious to study the effect on fruit set, color finish, and storage life of the apples. Although these varieties are subject to cork spot they apparently did not show this disorder during the tests.

In 1962, Simmons (147) reported on studies on the anatomy of the bitter pit areas of apples. The illustrations and text indicate that the author did not distinguish between bitter pit and cork spot in making his study. The text of this paper states that the anatomical studies were made on Golden Delicious and Starking apples sampled in September and October. It is further stated that

"A precise description of this disorder was recorded by Dunlap and Thompson (46), when they referred to bitter pit and deep pit of the apple. Samples selected for this study were those described as deep pit." Since Simmons' study appears to be concerned more with cork spot than bitter pit, the paper is reviewed with cork spot.

Anatomical studies made by Simmons disclosed much malformation in cellular structure with pectic protuberances extending into the intercellular spaces in the affected areas of apples. Abnormal growth of the cell is indicative of some stress occurring early in the growth of the fruit. Newly developed cells, arising from stimulated or injured cells appeared to be unable to compete with normal cells for nutrition for survival, thus the pitted areas enlarged. His studies tend to show why the tissues surrounding pits are abnormal. Although not dead or discolored, the tissues are found by processors to behave somewhat like scar tissues and to remain hard after cooking.

Barden and Thompson (11) made a detailed study of the anatomy of developing vascular tissues of the pedicel of the York Imperial apple. The study was to determine whether applications of boron sprays caused any changes in the vascular development. The study covered one year in which the incidence of cork spot was high and one year in which it was low. Vascular development was very similar for the two seasons, and they reported no indication of any relationship between vascular development and cork spot, or between boron sprays and vascular development.

Internal Breakdown

Unfortunately, the disorder considered here as internal breakdown is not only known by other names in other parts of the world, but may also be defined differently or poorly. Kidd and West 10/ discussed and illustrated a number of disorders under the name of internal breakdown. A 40-year collection of literature since their publication points clearly to the need for clarification of such terms as internal breakdown, mealy breakdown, physiological decay, Jonathan breakdown, senescence breakdown, and others.

In the United States internal breakdown has been characterized as a breaking down and browning of the interior of the apple. The riper side of the apple is often more seriously affected than the greener side and the blossom half is more susceptible than the stem half. Either a part or the entire fruit may be involved. The affected area usually starts at the peel and extends inward, but there may be a narrow margin of healthy tissues between the peel and the affected area. During the earlier stages, the flesh may be moist, but it later becomes spongy and mealy, especially in some varieties such as Grimes Golden, McIntosh, and summer varieties. The skin may retain its normal appearance, or become dull or brown. Some varieties crack badly. In brief, internal breakdown represents the end of the life of the apple or complete senescence.

Any internal disorder of the apple might be argued to be a kind of breakdown and, therefore, the name internal breakdown is not a desirable term. Perhaps senescence breakdown would be a more accurate name for this disorder.

Internal breakdown occurs mostly on large (1), overmature apples and on those that have been forced late in the season. Factors that increase susceptibility to the disorder are: holding apples on the trees too long, presence

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10/ Kidd, F., and West, C. Functional Diseases of Apples in Cold Storage. Dept. Sci. and Indus. Res. Food Invest. Bd. Spec. Rpt. 23, 1925.

of serious water core, delay in cooling, holding at too high temperature, and holding beyond the normal storage life.

Gerhardt and Allmendinger (57) tested the effect of a-naphthalene-acetic acid spray, as used for prevention of fruit drop, on ripening and storage physiology of Delicious apples. They concluded that if fruits are harvested within 1 or 2 weeks after application of the spray, their storage physiology and degree of ripeness are not influenced by the hormone. However, if apples are left on the trees beyond a reasonable time, the spray will increase the rate of ripening and the extent of losses from internal breakdown following water core.

Bünemann and others (34) found that internal breakdown during storage was associated with low potash content and large fruits.

Mattus (102), in Virginia, found that late harvesting and delayed storage were the principal factors causing internal breakdown of apples.

Phillips (127) reported that the prevalence of breakdown (internal or mealy breakdown) in McIntosh apples during the 1956-57 storage season was associated with apples from orchards with light crops.

Bramlage and Thompson (26) found that multiple boron sprays increased the incidence of internal breakdown of Jonathan apples during storage.

Phillips and Poapst (128) stated that internal breakdown in Lobo apples increased as the temperature was increased between 30° and 39° F. More internal breakdown was found in earlier harvested fruits than in later harvested fruits. This is the opposite of what others have found.

In studying the internal disorders of apples a clear distinction has been made in the United States between internal breakdown, internal browning, brown core, and soggy breakdown.

Soggy breakdown may develop in certain varieties of apples such as Grimes Golden, Golden Delicious, and Northwestern Greening if they are stored at 32° F., or slightly lower. Much of the review that follows probably belongs with the section on soggy breakdown, but because of the uncertainty it is placed with internal breakdown.

In a paper presented at the International Institute of Refrigeration, van Schreven (171) discussed breakdown of apples and pointed out the need for clarifying the terminology. She studied only the Jonathan variety and found what appeared to be more than one type of breakdown. She attributed breakdown to low temperature and also to slight water core, but she did not discuss them separately. She also stated that a high catabolic activity seemed to indicate a high susceptibility to breakdown.

In another paper van Schreven (172) reported two kinds of Jonathan breakdown: "glassy skin" and "sponginess." In general, the breakdown she described increased with a reduction in storage temperature, but delay in storing did not reduce the percentage of fruits affected. No relation was found between leaf and fruit content of nitrogen, phosphorous, potassium, calcium, and magnesium and the occurrence of breakdown.

Tinsdale (165) states that low temperature during the first 2 months of storage caused severe flesh breakdown in Jonathan apples.

Internal Browning

Internal browning has been observed wherever Yellow Newtown apples are grown. It is of economic importance, however, only in the Pajaro Valley in California, where the weather is cool and cloudy during the growing season, and at times in Washington and Oregon.

The tendency to develop internal browning is inherent in the fruits at harvest, but depends on storage temperatures of 30° to 32° F. in order to develop. Susceptibility seems increased in fruits that are large, or from light crops, those harvested late, or delayed in reaching storage.

Ryall and Uota (145) tested the effect of sealed polyethylene (150 gage) film liners on the occurrence of internal browning and general storage life of Yellow Newtown apples grown in the Pajaro Valley of California. Test and check lots were stored at 31° and 40° F. No serious internal browning occurred at 40°, but control was not ascribed to the film liners.

Jonathan Spot

Jonathan spot, a physiological disease, occurs on susceptible varieties wherever apples are grown. Jonathan spot is primarily a storage disorder associated with aging. While the disorder is worse on the Jonathan variety, it occurs frequently on Northern Spy, Rome Beauty, Winter Banana, and Golden Delicious and has been observed on a number of other varieties. In reporting the disorder on varieties other than Jonathan, there has been a tendency to introduce other names such as "Spy spot," "physiological spot," and "senescent spot" as synonyms of Jonathan spot.

Baker and Maxie (10) reported that Red Rome Beauty apples in storage are frequently subject to a physiological disorder characterized by small superficial brown or black spots at the lenticels. They state that the disorder resembles Jonathan spot and Spy spot. In a preliminary study they found that a combined treatment of activated charcoal and one-half pound of oiled paper per bushel retarded the spotting.

Smock (151) reported that "Spy spot" (Jonathan spot) was worse on the blush than the pale part of the fruit. He found that ringing large limbs caused the fruits thereon to be redder and more susceptible to Jonathan spot than fruits from nonringed limbs. Fruits from the outside of the trees were more susceptible than those from the shaded, inner portion. The disorder was worse on Northern Spy apples stored at 40° F. than on those stored at 32°. Air purification did not give control so Smock reasoned that volatiles were not the cause. Control was obtained by storing the apples in controlled atmosphere of about 5 percent carbon dioxide and 2 percent oxygen at 40°. (See section on Controlled-Atmosphere Storage, p. 89.)

Tomana (166) found that in plots with heavy nitrogen and phosphorous fertilizer applications, leaves and fruit tissues contained the most nitrogen and fruits spotted most severely. Earlier harvested fruits developed more Jonathan spot than late-harvested fruits. He states that open lenticels are necessary for Jonathan spot development, and that the primary cause of Jonathan spot is the infiltration of water through open lenticels. He believes that browning of the skin tissues of the spot are due to the oxidation of phenolic substances, chiefly l-epi-Catechin, by polyphenol oxidase.

Research workers in the United States do not consider that the nature of Jonathan spot is clearly understood, but its appearance on apples is believed indicative of a stage of senescence. Traas (167) states that Jonathan apples that are deeply colored, large, and picked late are most susceptible to Jonathan spot. He found that intensity of spotting was affected by the storage temperature and the degree of spotting when the fruits were stored.

Van Hiele (170) found the least Jonathan spot on Jonathan apples harvested early and stored immediately.

Staden (157) reported that in 1956 and 1957 Jonathan spot was limited by dipping fruits in diphenylamine, but that the results could not be confirmed the following season. Padfield (124) found no benefit from the use of diphenylamine in preventing Jonathan spot.

Martin, Lewis, and Cerny (98, 99) state that in the absence of other disorders there was a positive intercorrelation between percentage Jonathan spot, mean fruit size, and mean seed number both within and between trees. In one fruit size group on a tree, fruits with Jonathan spot had a higher mean seed number per fruit than sound fruit, and seed germination was greater. Within trees, if fruit size was controlled to give differing sizes, but with the same seed number, incidence of Jonathan spot was not altered. Between trees if fruit size was controlled to give fruits of similar size, but with differing seed numbers, the incidence of Jonathan spot varied. It is suggested that the relationship is due to the effect of seed number on the rate of ripening.

Dewey (45) reported that Jonathan spot was controlled during 7 months' storage of Jonathan apples in controlled atmospheres of 2.5 to 5.0 percent CO_2 and 3 percent O_2.

Scald

(Scald, because of its importance, is discussed in a separate section. See page 194.)

Soft Scald

Relatively little new information has been developed on this nonparasitic disease. Its occurrence is sporadic, even on susceptible varieties like Jonathan and Rome Beauty (142). Sometimes it is serious on Delicious apples grown in the Pacific Northwest. Soft scald, or deep scald, is worse on large apples and in light crop years (39). It is considered a low-temperature disorder, being most severe at 31° to 32°. It seldom develops at storage temperatures of 36° to 38° F. Several investigators reported that soft scald is most severe on later or more mature pickings (39, 58, 59). Ginsburg (59) examined fruit from four pickings over a 5-year period and found a high incidence of soft scald on the third and fourth pickings when stored at 31°. For these late pickings, the extent of soft scald became progressively higher at 3-, 4-, 5-, and 6-month examinations. Yet the injury had its origin in the first month or two of cold storage.

Carne (39) and Gerhardt and Sainsbury (58) reported soft scald was worse when there was a delay between harvest and cooling. When there was a delay of one week at 70° F. before storage at 31°, soft scald was increased over immediate storage (58). Gerhardt and Sainsbury found that two conditions were necessary for soft scald development on Delicious apples: (1) A critical stage of metabolism accentuated by delayed storage or advanced maturity and (2) a storage temperature of 32° F. or below. If both were present, soft scald was often severe. They recommended 8 weeks' storage at 34° for Delicious apples before storage at 31°, if the fruit was susceptible to soft scald. However, with good handling and optimum maturity Delicious apples can be placed directly at 31°. Gerhardt (unpublished) controlled soft scald in Jonathan and Delicious apples by packing them in sealed 1.5 mil polyethylene liners.

Padfield (123) tested the idea of gradual temperature reduction from 38° F. to 35° to 32° and other combinations. Soft scald occurred in all treatments, although it usually is not expected if fruit is held at 36° or above. He concluded that soft scald is sometimes severe and not related to storage temperature. A storage temperature of 37° to 38° was recommended for varieties susceptible to soft scald.

Water Core

Fruits affected with water core have a water-soaked appearance of the involved flesh. When excessive the affected tissues of most varieties will break down in storage causing considerable loss of fruits. The disorder is most prevalent in mature fruit harvested relatively late in the season. Less extensive water-core affected tissues will often recover in storage and the fruit will be salable but have relatively short shelf life.

Schomer (146) in a comprehensive review of the factors associated with the development of water core pointed out that the real causes are high temperatures, intense sunlight, and a high sugar concentration in the cell sap. He said that tissue breakdown following water core is unpredictable. In extreme cases breakdown may occur before the tissues make normal recovery, while in other cases affected tissues may temporarily recover their normal appearance, then show varying intensities of browned flesh in the core area.

Hill and MacArthur (71) confirmed the accepted view that water core was more prevalent under high nitrogen conditions. They also found it more prevalent on young trees first coming into bearing than on older ones.

Ceponis and Friedman (40) observing extensive water core in Missouri-grown Lady apples found a progressive reduction in water core during cold storage and during holding at 70° F. Separation prior to storage was made as to externally nonvisible and externally visible water core. The smallest size apples had the least water core at each examination at 3 and 5 months' storage. Internal breakdown developed in 7 days at 70° after 3 months at 35° in the apples having externally visible water core; it became more prevalent after 5 months' storage. Breakdown was more severe in the larger apples (2 inches and over) that had shown externally visible water core at arrival.

Birth 11/ describes tests for detection of water core in Winesap apples using the new technique of light transmission through the whole, intact fruit. He reported that an optical density difference between 805 and 750 mμ (Δ O.D. 805-750) was indicative of water core. There were problems of temperature sensitiveness in the measurement and the confounding factor of internal browning, which could indicate erroneously, a sound apple. These problems can be overcome by making two measurements; Δ O.D. (805-830) to indicate internal browning and Δ O.D. (805-750) to indicate water core.

Olsen, Schomer, and Birth (121) found that water-cored apples could be successfully separated into several categories based on severity of the disorder, by means of a difference meter measurement (difference in O.D. 760-0.8 O.D. 815 mμ). The difference meter effectively rated the severity of water core in apples. Correlations between meter readings and two other methods of scoring were highly significant. Temperature changes of the fruit caused some variation in light transmittance readings.

11/ Birth, G. S. Determination of Water Core in Winesap Apples. (Unpublished report.) 1960.

Bramlage and Thompson (26) found that multiple boron sprays increased the incidence of water core in Jonathan apples.

Porritt, McMechan and Williams (133A) describe a flotation method for segregation of water core apples. Satisfactory separation in Delicious apples could be obtained with solutions of ethyl, methyl, and isopropyl alcohol adjusted to a specific gravity of about 0.877.

Probably, the best known procedure for dealing with water core is to watch for its development in the orchard during harvesttime, particularly in fruits well exposed on the southwest sides of trees (146). The fruits should be picked before extensive water core develops.

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SCALD

Apple scald is still a major source of loss during late storage of apples in many parts of the world. It is a superficial physiological disorder (often called superficial scald) of the skin characterized by irregular-shaped brown blotches, which makes fruit unattractive or even unsalable on the fresh market. The browning may be light in some seasons and on some varieties, or it may be severe and progress until much of the surface is dark brown and sometimes roughened.

Most of the research on scald prior to 1945 was reviewed by Smock and Southwick (112). [1] More recent reviews of the factors affecting scald and scald control research were published by Pentzer and Heinze (76) in 1954, Marcellin and Leblond (49) in 1957, Fidler (16) in 1959, Ginsburg (23), Martin and Lewis (52), and Smock (109) in 1961.

The cause of scald is still unknown although many possibilities have been investigated. The usual theory is that some volatile substances produced by the fruit accumulate in the skin and directly or indirectly are responsible for the death of susceptible tissue. However, the volatile theory is becoming increasingly controversial, and whether volatile substances are actively involved in scald is still unknown (6, 14, 17, 26, 42, 43, 44, 75, 99, 112). Bain (1) found that scald symptoms were due to death of hypodermal cells. Epidermal cells were not affected unless scald was very severe.

Later Bain and Mercer (2) examined Granny Smith apples by electron microscopy. The first symptom of scald detected was the formation of an additional electron-dense material in close association with a normal constituent of the vacuoles of hypodermal cells. The additional material accumulated on the tonoplast as scald became more severe, and the protoplasts became disorganized, tan and increasingly electron dense. Following this the cells collapsed radially, forming the dark brown sunken lesion associated with severe scald.

Shutak and others (100) found that scald did not develop on areas of fruit surface that had part of the cutin removed. The cuticle may act as a barrier to the escape of substances responsible for scald. Siegelman and Schomer (101) and Metlitskii and Tsekhomskaya (59) reported that scalded apple skin had a lower rate of respiration than nonscalded skin, probably due to cell destruction in scalded tissue. Patterson (75) showed that the scald reaction was enzymatic.

In 1958, Metlitskii and Tsekhomskaya (59) proposed that scald should be regarded as a disturbance of metabolic equilibrium with a deviation of respiration towards anaerobiosis. This resulted in alcohol and acetaldehyde accumulation in tissues. They found that during storage there is a noticeable decrease in the air permeability of apple skin. Also, in apples affected by scald, skin permeability is much lower than in healthy apple skin.

Dilley et al. (13) proposed that apple scald is composed of two physiologically distinct phases; one of anaerobic induction and one of aerobic development. Brief nitrogen treatments of 36 to 108 hours at 20° C. (68° F.) were used to induce scald on Rome and McIntosh apples. It is not known if scald could be anaerobically induced immediately after harvest because the fruit used in this test had been stored 3 months before nitrogen was administered.

Role of Volatiles

Apples give off various volatile materials some of which may be responsible for scald development. Meigh (56) found that acetone and acetaldehyde were two of the most abundant volatiles produced by apples. He found no correlation between high carbonyl evolution and heavy incidence of scald. Griffiths and Potter (26) stated that a high concentration of volatile substances in the storage atmosphere coincides with a marked increase in scald.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 204.

Smock and Neubert (111) also linked scald with volatiles. When Rhode Island Greening apples were stored with other varieties, 91 percent of the Greening scalded; stored alone 36 percent scalded; and stored alone in a room with an air purifier only 1 percent scalded. Southwick (115) reported a possible relationship of scald and volatiles, when he found high volatile production from McIntosh in 1941 and much scald. In 1942, less volatiles were produced and less scald developed. Thompson and Huelin (127) found that early picked fruit gave off less volatiles than late-picked fruit, even though early picked fruit is more scald susceptible.

Fidler and North (17) found that ethylene, present in or added to apple storages, did not increase scald. Stoll (124) pointed out that whether volatiles induce scald or not depends on their chemical nature, their concentration, and the duration of their action. However, the resistance of the skin, which varies with its structure, its composition and its physiological age, appears to be of equal importance. Hilkenbaumer (42) found that absorption of aromatic volatiles by the cuticle contributes to the development of scald and by removing them from the cuticle by scrubbing, scald can be avoided. Buchloh (6) suggested that scald is caused by a substance in the skin, which becomes toxic during long storage at low temperatures, but is diffused from the skin under conditions of alternating temperature or forced ventilation.

Several other investigators have studied the chemistry of volatiles and the effect of volatiles on scald (28, 44, 45, 61, 62, 64, 112, 120, 126, 132, 137). Okamoto (63) produced a scald-like injury by treating apples with formic acid, acetic acid, amyl alcohol, hexyl alcohol, and esters containing 6 to 8 carbon atoms. Huelin and Kennett (44) tested the effect of 19 volatile products on scald development. At a concentration of 1 mole in 10,000 moles of air, only butyric and caproic acids, and butyl and hexyl acetates significantly increased scald in fruit protected with oiled wraps.

Effect of Weather

Scald susceptibility varies markedly from season to season. Scald is usually most severe in years when the climate is hot and dry during the last few weeks of the growing season (52, 106, 131). In England, Fidler (15) found a strong correlation between scald in storage and high evaporation in relation to the amount of rainfall before harvest. Uota (131) controlled the temperature around the branches of McIntosh trees during the last 3 weeks before harvest. He reported that high night temperatures gave 100 percent scald and low night temperatures, only 2 percent. Work of a similar nature by Merritt and others (58) and Morris, Merritt, and Stiles (60) showed preharvest air temperature to be an important factor. Scald susceptibility was greatly reduced after a sufficient number of hours below 50° F. had elapsed before harvest. With Stayman apples, storage scald was minimized if picking was delayed until 150 hours of temperature below 50° had accumulated after September 15.

Effect of Nutrition

Relatively little new experimental data is available on the effect of orchard nutrition on scald. Southwick, Weeks, Drake and Olanyk (118) reported that foliar levels of nitrogen of 2.26 percent and higher increased the susceptibility of Red Delicious to scald in comparison to fruit from trees having an average leaf nitrogen of 2.12 percent on a dry-weight basis. Similarly,

foliar levels of potassium of 1.97 percent or higher increased fruit susceptibility to scald in comparison to fruit from trees where the potassium level was 1.41 percent.

Effect of Fruit Size

Large apples are usually more susceptible to scald than small apples (16, 23, 109). However, in a year when scald is severe even most small apples will scald. Ginsburg (23) in South Africa found no difference in scald susceptibility between size 113 and size 216 apples.

Fruit Maturity

It has long been recognized that early picked fruit or immature fruit scalds worse and often sooner than mature fruit (4, 23, 29, 33, 41, 52, 59, 65, 68, 89, 117, 121, 128, 133, 134). With Granny Smith apples in Australia, Tindale (128) demonstrated a fairly sharp break in scald susceptibility as fruit matures on the tree. Scald was high before a certain picking date, and much lower thereafter.

Smock (109) reported an exception to the general rule. Overmature McIntosh stored in controlled atmospheres tend to scald worse than fruit picked earlier. Hardenburg and Siegelman (38) reported overmature Golden Delicious stored in polyethylene liners scald worse than early picked fruit.

Effect of Delayed Storage

A delay in getting apples from the orchard into refrigerated storage has not consistently increased or decreased the extent of scald (23). Padfield (65, 67) found that delayed storage of Granny Smith apples increased scald and increased yellowing. Southwick (117) found that a delay in storage of more than 1 day at 70° F. after harvest increased the amount of scald developing on both McIntosh and Cortland held in CA storage. Rose, McColloch, and Fisher (90) said delayed storage increased scald if ventilation around the fruit was poor during the delay. Fidler and North (17) found that delayed storage of 6 to 12 days at 65° increased scald of Bramley's Seedling and Edward VII. Denmead, Vere-Jones, and Atkinson (11) reported that fruit held 6 days at ambient temperature before storage were less susceptible to scald than those placed in cold storage immediately. Stevenson (121) found that delayed storage reduced scald but increased wastage from mold, breakdown, and softening. It is generally agreed that delayed storage is not a practical approach to scald control because of ripening during the delay.

Predicting Scald Intensity

Early prediction of the scald susceptibility of various lots of apples would be most useful to the storage house manager. Smock (109) has shown that storing samples for 6 weeks at 70° F. in 1.5-mil nonsealed polyethylene box liners will produce scald on susceptible fruit and thus give useful information. However, the prediction method tended to underestimate the scald that eventually developed in storage or on removal from storage.

Scald Control

The standard method of control has been to avoid picking too early and to use mineral-oil-impregnated wraps or shredded paper when storing scald-susceptible varieties. Oiled wraps, used commercially on many varieties since 1920, usually reduced scald but have not always provided adequate control. In Russia, apples are sometimes packed in wood shavings to retard scald (59). It is hoped that commercial use of the new chemical scald control treatments, described later, will greatly reduce losses in the future.

Oils and Waxes

Certain oils and waxes have reduced scald in controlled experiments but they are not used commercially. Shutak and Christopher (97, 98) found that treating apples before storage with a 3-percent mineral-oil emulsion controlled scald on Cortland apples. A 5-percent mineral-oil orchard spray prior to harvest reduced scald but caused some leaf injury. Smock and Southwick (112) reported that results were inconsistent when apples were coated with mineral oil. In some years it gave no scald control. They reported that a wax designated as 489AM significantly reduced scald on Rhode Island Greening apples. Hall, Sykes, and Trout (30, 31, 32) studied extensively the coating of apples with oils. An alcohol solution of 8 to 10 percent castor oil and shellac used as a coating reduced scald, but was less effective than good oiled wraps. They reported that oil coatings reduced scald more than controlled-atmosphere storage.

Oiled Paper

Oiled paper containing 15 to 20 percent of its finished weight in mineral oil, used as individual wraps or at the rate of three-fourths pound of shredded paper per bushel, has been a standard scald control measure for many years. Although oiled paper is often effective, its use has declined because of costs of applying the wraps and new handling methods. Many reports issued since 1945 still show the effectiveness of oiled wraps (4, 14, 15, 23, 27, 37, 41, 46, 65, 66, 68, 69, 77, 86, 89, 112, 113, 133, 135). Fidler (14) showed that oiled wraps provided better scald control than air purification filters in the storage room. Smock and Southwick (113) found that air purification plus the use of oiled wrappers provided better scald control than either used alone. Whittaker (135) in Australia showed that the scald susceptible variety Granny Smith should not be stored more than 2 months without the protection of oiled wraps. Padfield (69) found that rewrapping apples with fresh oiled wraps after 3 months' storage did not improve scald control. Hall (27) pointed out that the oil content of wraps may decrease markedly during storage from one season to the next. The loss can be minimized by keeping oil wraps well protected with waxed paper or polyethylene film.

Air Purification and Ventilation

Many attempts have been made to remove volatiles from apple storages, assuming that they may be causing scald. Activated carbon or brominated activated carbon filters reduced scald in several studies (14, 20, 21, 104, 105, 113, 132). In other studies, air purification did not appreciably reduce scald

(9, 19, 22, 23, 77). Fidler (14) and Gerhardt, Sainsbury and Siegelman (22) reported that use of oiled wraps was a more efficient and economical method of controlling scald than air purification with filters. Kuc, Henze, and Quackenbush (47, 48) reported that alkaline potassium permanganate air scrubbers reduced scald. A later report by Workman and Patterson (137) showed no control. Air washing or scrubbing the storage air with water reduced scald according to reports by Buchloh (7) and Stoll (123), but this was not substantiated by Ginsburg (23).

A recent report by Hall, Scott, and Riley (28) supports the "volatile theory" on the cause of scald. Scald was reduced by increased ventilation of apples in both regular and controlled-atmosphere storage. Also, the more ventilated apples or outer apples of a packed box scalded less than inner apples. However, Smock (109) found that ventilating Cortland and Rhode Island Greening apples with eight air changes per hour did not reduce scald.

(See also section on Volatiles and Atmosphere Purification in Storage.)

Ozone

Neither Schomer and McColloch (94) nor Stevenson (121) found the use of ozone in storage rooms to be of much value in controlling scald. Its main value was in controlling surface mold on packages and walls and removing storage odors. Ozone reduced scald on some varieties, such as Arkansas, but there is danger of injury to the fruit.

Carbon Dioxide

Treatment of apples with 30 to 60 percent carbon dioxide for 3 to 10 days in storage immediately after harvest reduced scald markedly in several varieties, according to studies at the Rhode Island Experiment Station (8, 80, 81, 82). This treatment caused some injury on Baldwin and McIntosh varieties and is not used commercially.

In 1963, Roberts, Hall, and Scott (88) reported that scald is decreased by increasing the carbon dioxide concentration, and increased by increasing oxygen concentration in the storage atmosphere. These findings on carbon dioxide are contrary to many others, but the authors point out that results in many tests have been confounded by using carbon dioxide absorbents or restricting ventilation.

Gamma Irradiation

Phillips, Macqueen, and Poapst (78) found that McIntosh apples irradiated with 288,000 rads developed less scald than nontreated apples after 5 months' storage at 32° F. Smock and Sparrow (114) treated Cortland and Rhode Island Greening apples with dosages as high as 40,000 roentgens of gamma radiation and reported no commercially important benefits. In 1964, Massey, Parsons, and Smock (53) reported that radiation treatments resulted in progressively less storage scald with increasing dosage on Rome, McIntosh, and Cortland apples. A 100-krad treatment for 6 to 12 hours essentially controlled scald, except on early picked Romes.

Heat Treatments

Stoll (123) in Switzerland found that a 5 to 10 minute warm water dip (104° F.) before storage gave good scald control. Patterson (75) also reported that a hot-water blanching treatment controlled scald. In 1962, Hardenburg (unpublished) noted that a 2-minute dip in 120° F. water, or 1 minute in 130° water, markedly reduced scald on Stayman apples. However, on several other varieties, these heat treatments produced a scald-like injury.

Storage Temperature

On many varieties little scald develops if fruit is held continuously at low temperatures of 30° to 32° F. The low temperature retards scald, but fruit may eventually develop as much scald following low-temperature storage as at somewhat higher storage temperatures (27, 33, 90). Martin and Lewis (52) stated that symptoms of scald show earlier at 38° F. than at lower temperatures, but the severity is worse at lower temperatures.

Smith (103) reported that warming Bramley's Seedling apples at 2-week intervals to 60° F. for 5 days reduced scald. There was a progressive reduction in the percentage of apples with scald with warming from the 2d to 12th week in storage and a complete absence of scald when apples were warmed in the 16th and 20th weeks. In the 30th week scald again became very marked. Melville and Hardisty (57) and Ginsburg (24) suggested dual-temperature storage for Granny Smith apples. Scald was reduced when the storage temperature was 40° F. the first month, 36° the second month, and 32° thereafter (57). Padfield (69) working with the same variety, found that reducing the temperature from 37°-38° to 31°-32° after 4 weeks' storage did not assist scald control. Gradual temperature reduction and warming at intervals have the disadvantage of increasing the rate of fruit ripening.

Controlled-Atmosphere Storage

Scald is almost always lower in controlled-atmosphere storage if the oxygen is rapidly lowered to 3 to 5 percent (17, 51, 104, 109). It is important that the oxygen level be low during the first month or two of storage for good scald control (104). If oxygen is reduced to an intermediate level of 10 to 16 percent, scald is often more severe than in air storage (51, 109). Smock (109) has presented much data on McIntosh, showing that when some carbon dioxide was present low oxygen levels resulted in less scald than high oxygen. Controlled atmospheres reduced scald on all varieties tested except Cortland apples stored at 38° F. Martin and Cerny (51) showed that 3 percent oxygen in the absence of carbon dioxide was much better than 16 percent oxygen and 5 percent carbon dioxide for varieties susceptible to scald and breakdown. Granny Smith apples can be kept in good condition for at least 7 months at 32° F. under controlled-atmosphere conditions of 5 percent carbon dioxide and 2.5 percent oxygen or 5 percent carbon dioxide and 16 percent oxygen (96). For best scald control this variety should also be wrapped in diphenylamine-treated tissues. Patterson (75) reported that scald was reduced by lowering oxygen to 1 percent or by increasing carbon dioxide to 12 percent. Carbon dioxide above 12 percent increased scald.

Film Box Liners

The effect of polyethylene box liners on scald is closely associated with the extent to which the atmosphere is modified. Sealed polyethylene liners usually reduced scald and often largely controlled it, if the oxygen within the liners was maintained at a low level of 2 to 6 percent (29, 34, 36, 38, 49, 75, 91, 92, 108, 110, 136). If oxygen reached an equilibrium at a higher level within liners, scald was not reduced and was sometimes increased (34, 49, 110, 136). Rasmussen (87) reported higher scald for several varieties in sealed liners even with oxygen at a low level of 3 to 6 percent and carbon dioxide at 6 to 8 percent. Hardenburg and Anderson (34) obtained the best scald control when oiled wraps or chemical scald inhibitors were used with sealed 1.5-mil polyethylene liners. Patterson (75) suggested that low oxygen and high carbon dioxide levels within sealed film liners may act synergistically in reducing scald.

Nonsealed or perforated film box liners usually increase scald incidence (34, 36, 38, 71, 108, 110). Within these liners the atmosphere usually contains 17 to 20 percent oxygen and 1 to 2 percent carbon dioxide (34). Ulrich and Leblond (130) reported no increase in scald on the Belle de Boskoop apple in nonsealed liners.

Relative Humidity

A high relative humidity of 90 percent or above is generally thought to favor scald development (16, 112). However, high humidity is necessary to minimize moisture loss so low humidity is not a practical approach to scald control. Recently, Hilkenbaumer (42) in Germany reported that high humidity (95 percent) reduced scald.

Intervariety Effects

The influence of one variety on the scald of other apple varieties has been studied by several investigators (112, 120, 124). Smock and Southwick (112) noted that the vapors of McIntosh apples increased scald on Cortland and Rhode Island Greening apples. Stoll (124) stored scald-susceptible and scald-resistant varieties together and found that the volatiles of susceptible varieties induced more severe scald symptoms than those of resistant varieties. The presence of one susceptible variety increased scald symptoms in another susceptible variety. When a resistant variety was stored with a susceptible variety, scald was reduced in the susceptible variety in seven out of nine tests. On the other hand, Stoll found that scald was induced in varieties considered resistant, if they were stored in close contact with susceptible varieties.

Chemical Scald Inhibitors

Many chemicals have been evaluated as possible scald inhibitors, but until recently none, other than mineral oil in fruit wraps, were approved for use. Crude bexane (44), diphenyldimethylurea (119, pp. 21-22), and growth regulators (93) were reported to have scald controlling properties, but they are not used commercially. In 1955, Smock (107) discovered the inhibitory effect of dephenylamine ($C_{12}H_{11}N$), usually designated as DPA, which provided

excellent scald control. DPA was approved for use on apples in the United States in 1962, with a residue tolerance of 10 p.p.m. In 1957, Smock (108) reported that ethoxyquin (6-ethoxy-1,2,-dihydro-2,2,4-trimethylquinoline) also had scald-reducing properties. Ethoxyquin was approved for use in 1960 and is sold commercially as "Stop-Scald." A residue tolerance of 3 p.p.m. was established for Stop-Scald.

Since the early research on these two scald inhibitors, their effectiveness has been widely confirmed with other varieties and with various application procedures: United States (5, 34, 35, 37, 54, 55, 83, 95, 108, 109, 116, 117, 138), Canada (18, 79, 85), Great Britain (16), Holland (119, 120), Germany (42), Italy (25), Australia (29, 43, 50, 52, 122, 129), New Zealand (11, 39, 40, 70, 74), Switzerland (123), and South Africa (23, 24). In tests in which both DPA and Stop-Scald were included, DPA usually gave more complete scald control. Both materials usually provide much better scald control than is obtainable with oiled wraps, and are effective on most varieties.

Sims (102) studied the influence of DPA on apple skin and found that DPA stimulated the production of yellow ground color on exposure to light and warming.

Yatsu (138) in studying the mode of action of DPA found that it did not inhibit cytochrome oxidase activity appreciably. DPA was able to act as an uncoupler of oxidative phosphorylation, and it inhibited the succinoxidase system of apple fruit mitochondria. Baker (3) noted that diphenylamine inhibits electron transport in plant mitochondria.

Residues of DPA were found to be mostly in the outer 2 to 4 mm. of the apple (39, 40). A dip in 1,000 to 2,000 p.p.m. DPA left an initial residue of 4 to 8 p.p.m., which declined to 3 p.p.m. or less after 4 to 7 months' storage (5, 11, 23, 29, 40). Denmead, Vere-Jones, and Atkinson (11) reported that varieties differ by more than tenfold in DPA uptake for the same treatment. Hall, Scott, and Coote (29) stated that about 0.1 mg. of DPA was needed per average-sized apple to control scald.

Several investigators reported that DPA used as a postharvest dip was an effective scald inhibitor in regular cold storage, in CA storage, and in polyethylene-lined boxes (29, 34, 37, 109, 122).

Reports of injury from experimental use of DPA are fairly numerous (18, 25, 34, 37, 70, 83, 109, 125). Sometimes this has been a scattered skin burning from DPA crystals picked up on the skin; sometimes the injury has been concentrated in stem or calyx cavities from drainage of DPA solutions. The use of wettable powder formulations of DPA have since greatly reduced the chance of chemical injury (37, 55, 83, 109). An 83-percent wettable powder was the type approved for use in the United States.

Stop-Scald used at 1,800 to 2,700 p.p.m. usually has cuased no injury, except when it was applied as a preharvest tree spray when temperatures were above 80° F. This appeared as slight brown stains on the lower side of fruits (37, 54, 109). Stop-Scald at a concentration of 0.3 percent as a 15-second dip caused injury on several varieties tested in Switzerland (125).

Both DPA and Stop-Scald gave the best scald control when used as a fruit dip (10, 23, 24, 25, 35, 37, 52, 55, 70, 72, 83, 108, 109, 116, 122). Spraying loose fruit on rollers, spraying filled field boxes, and dunking filled boxes are other application methods. Box sprays and box dunks sometimes resulted in slight DPA injury to fruit in bottom layers. Spraying trees with scald inhibitors was one of the least effective application methods and was more wasteful of materials (10, 37, 55, 74, 108, 109, 117). However, tree sprays often gave better scald control than oiled wraps. Tree sprays to be effective must be applied within a day or two of harvest.

Dilley and Dewey (12) found that fruit in 20-bushel bulk boxes could be successfully dunked in a tank containing DPA at a concentration of 2,000 p.p.m., using a modified forklift truck. Use of the spreader-sticker "Plyac" with DPA eliminated DPA injury, sometimes encountered in treating Red Rome apples.

In Massachusetts, Southwick (117) found that neither preharvest sprays nor postharvest dips with DPA or with Stop-Scald gave good scald control on McIntosh or Rome Beauty apples in regular cold storage. The best approach to scald control with these varieties in Massachusetts appeared to be CA storage.

Martin (50) reported a steam tunnel application procedure, whereby fruit is coated with DPA from the steam of a boiling DPA solution. After a brief treatment, the water evaporates leaving a fine deposit of DPA. Denmead, Vere-Jones, and Atkinson (11) in New Zealand described an oil-water emulsion treatment with DPA using Octaro oil. The fruit is first wet with water, then drained, then drenched with the emulsion for 1 to 10 minutes to get the needed uptake for the variety, then drained for 30 seconds before rinsing with water. Padfield and Clark (73) found this procedure satisfactory for controlling scald on Delicious, Dougherty, and Rome Beauty varieties. An uptake of less than 5 micrograms of DPA per square centimeter provided scald control. Hardenburg and Anderson (37) and Mattus (55) found that applying Stop-Scald or DPA with a drip applicator using a revolving brush gave nearly as good scald control as a dip treatment. This method is the same as that used for waxing some types of produce. It is a very economical method of applying scald inhibitors.

Pierson and Schomer (83) washed apples 1 to 4 weeks after a DPA dip. With Delicious apples, if they were washed in less than 3 weeks, the maximum benefit from DPA was not obtained. Winesap could be washed 2 weeks after being dipped in DPA and still have excellent scald control.

DPA wraps and DPA treated oiled wraps provided good scald control in numerous tests and were much superior to conventional oiled wraps (10, 23, 34, 35, 37, 52, 55, 96, 109, 122, 123). The most acceptable quantity of DPA was 1.5 mg. per sheet. Ginsburg (24) had good results with wraps containing 0.7 mg. per sheet on South African varieties. Of the two types of DPA wraps, DPA treated oiled wraps were superior to plain DPA wraps (37, 109).

Raphael and O'Loughlin (86) packed Granny Smith apples in corrugated cell cartons which had been treated with Stop-Scald and obtained effective scald control.

Mattus (54, 55) and Hardenburg and Anderson (37) noted that good coverage with Stop-Scald was necessary for scald control. Since Stop-Scald fluoresces under ultraviolet light in the dark, it is relatively easy to check the fruit coating with various application methods. Coverage was poorer on early picked fruit than on fruit picked later. Good coverage was obtained easily on Stayman and Winesap varieties, but coverage was poorer on Delicious, Jonathan, and Grimes Golden varieties. Coverage was improved by lengthening the time of treatment, increasing the emulsion concentration, or raising the emulsion temperature to 100° or 120° F. The latter was particularly effective as a method of improving coverage with scald inhibitors. Padfield, Atkinson, and Clark (72) also found that warming Stop-Scald treating emulsions to 100 to 110° F. increased the uptake of the inhibitor. However, for New Zealand varieties warming the treating liquid was unnecessary for satisfactory scald control. Coverage also was better on warm (70°) than on cool (40°) fruit (37, 54). Daines (10) found that Stop-Scald used on Stayman was very effective when apples were warm, but its efficiency was sharply reduced when apples were cold (32°) when treated.

Shipping containers used in marketing apples treated after harvest with chemical scald inhibitors must be properly marked with a label, such as: "Treated with Ethoxyquin to Retard Spoilage (Scald)."

Use of these chemical inhibitors in years ahead should greatly reduce losses in storage and marketing of apples. But in a severe scald year, scald will still cause waste. Some countries will continue to prohibit the use of chemical inhibitors and some growers will prefer to use other methods to minimize scald losses. The suggestions of Stoll (125) should be of interest to all who might encounter scald during storage:

1. Cultivate scald-resistant varieties or sports.

2. Prune trees to allow adequate light exposure on fruit.

3. Avoid picking too early or too late.

4. Store fruit promptly at the recommended temperature for the variety. Usually rapid cooling is desirable.

5. Provide high relative humidity of 85 to 90 percent in storage; avoid humidity above 92 percent for scald-susceptible varieties.

6. Provide air purification and good air circulation in storage rooms.

7. Use controlled-atmosphere storage for late storage for adaptable varieties.

8. Check fruit periodically for scald symptoms and market before scald losses are incurred.

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